How It is Made

Describing in simple language how various Machines and many Articles in common use are manufactured from the Raw Materials

By

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"The Romance of Mining,"
"How It Works,"
etc., etc.

THOMAS NELSON AND SONS

London, Edinburgh, Dublin, and New York

AUTHOR'S NOTE

I BEG to thank the following gentlemen for the help they have given me in the revision of MS.: Messrs. F. Matthews, W. B. Judd, R. J. Hardy, G. Rose, J. M'Arthur, James S. Hoyle, W. Gray, W. B. Williams, C. Hodgson, E. C. Martin, E. G. Allen, W. M. Green, W. J. Mitchell; and the following firms for permission to visit their factories: The New Hudson Cycle Co.; The Rudge-Whitworth Cycle Co.; R. W. White and Co.; John Broadwood and Sons; Price's Patent Candle Co.; The Worcester Royal Porcelain Co.; J. B. Edwards and Co.; Huntley and Palmers, Ltd.; Wm. Cooke and Co.; Brown, Bailey, and Co.; Joshua Hoyle and Sons; Vickers Sons and Maxim; Sanderson Bros. and Newbould, Ltd.; J. Rotherham and Co.; The Daimler Motor Co.; J. English and Co.; Henry Millward and Sons; Butler and Spragg, Ltd.; J. T. Davis, Ltd.; Bullivants, Ltd.; Mappin and Webb; G. Goodman, Ltd.; A. E. Reed and Co.; R. Orrock and Co.

I am also indebted to Messrs. Jos. Rodgers and Co., and to Messrs. Horrockses, Crewdson, and Co., for selections of photographs for illustrations.

PREFACE.

In a primitive society every person of sufficient age is primarily a worker with his or her hands. As a nation develops, not only do head work and hand work become more and more distinct, but occupations of all kinds tend to run in narrower grooves. Competition now forces us to pay great respect to the proverb, "Let the shoemaker stick to his last;" and it has come about that the majority of even well-educated people in industrial countries are largely ignorant of the processes by which articles in common use are manufactured. It must be admitted, nevertheless, that this ignorance results from circumstances rather than from choice; for in any exhibition where something is being made visitors cluster round to watch the creation even of an article which may not be at all interesting in itself. The visitors' book of any large factory that opens its doors to the public, and is within easy reach of large centres of population, reveals the same desire for information.

I have therefore been encouraged to make a tour of inspection among our industrial centres, and to record in these pages what I learnt from personal observation. As it was obviously impossible to give even short descriptions of all manufacturing industries in the space at my disposal, I have been obliged to select a convenient number of manu-

factures for treatment. Some, such as iron, steel, and cotton, could hardly, on account of their prime importance, have been omitted. Others, again, have been chosen because the thing manufactured is of interest to the general public. I cannot hope that my choice will pass unchallenged, for in a matter of this sort any one person's choice is influenced by his or her individual preferences. But I venture to think that a sufficiently wide field has been covered to give the reader a good idea of the nation's workshops.

Want of space has compelled me to limit my descriptions to a plain statement of what I saw, and to omit anything beyond the briefest reference to the history of an industry. Wherever it seemed advisable, the accounts written were submitted to experts, who in all cases kindly revised them with great care. I owe a debt of gratitude to them, and to the many firms who allowed me to visit their premises, and showed personal interest in the success of my industrial explorations.

It is my sincere wish that the perusal of this book may do for the reader what the writing of it has done for me—make him realize what ingenuity and toil are devoted to the manufactures which render living comfortable and the country prosperous. Wordsworth has confessed to being deeply moved by the sight of "the meanest flower that blows." Might not a match, a pin, or a needle—worth but a fraction of a penny—also stimulate a poet who has seen it in the making? A. W.

UPLANDS, STOKE POGES, BUCKS.

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CONTENTS.

HOW IT IS MADE.

Chapter I.

MONEY-MAKING.

The Royal Mint—Gold and silver bars—The melting-houses—The rolling-room—Cutting the blanks—Marking—Annealing—The coining-presses—Weighing the coins—A very delicate automatic machine—Counting by machinery—Medals—Making a die—A popular fallacy.

THINGS are manufactured to be bought and sold. Buying and selling imply, in most cases, the transference of coin from one person's pocket to that of another. So, after thinking over for some time the question of priority of subject, I have decided to open this book with a chapter on the making of the "coin of the realm," as conducted at the Royal Mint, a large building situated a few hundred yards to the north-east of the famous Tower of London, which itself was the seat of coinage until the erection of the present Mint in the year 1811.

The Royal Mint is not at all imposing as seen from the street—just a long block of offices on the farther side of an open courtyard. One would never suspect that from some workshops at the rear of this block proceed most of the gold and silver coins issued in the British Empire, and all the medals issued to the navy, army, and royal societies. It is a unique factory, as far as the empire is concerned, since it has the sole right of manufacturing a certain class of article. Clever gentlemen who set up rival factories in secret places, and happen to be caught at work, are lodged for a long period at the country's expense, under conditions in which money is of very little use to them.

Behind the office block is a quadrangle surrounded by low buildings. Entering a door on the left, the visitor finds himself in a room where ingots of gold, silver, and copper are weighed very carefully before being handed over to the workmen. Great exactness is characteristic of all business at the Mint. A certain weight of metal is given out, and it must return to the office in the shape of a certain number of coins. If a single coin be missing, it is hunted for till found. Even the dust in the workrooms is collected and put in the melting-pot to recover all the minute particles of metal it contains. And, as

we shall see, exactitude within very narrow limits in the dimensions and weight of the coins themselves is enforced.

Gold comes to the Mint as ingots of 400 oz.;

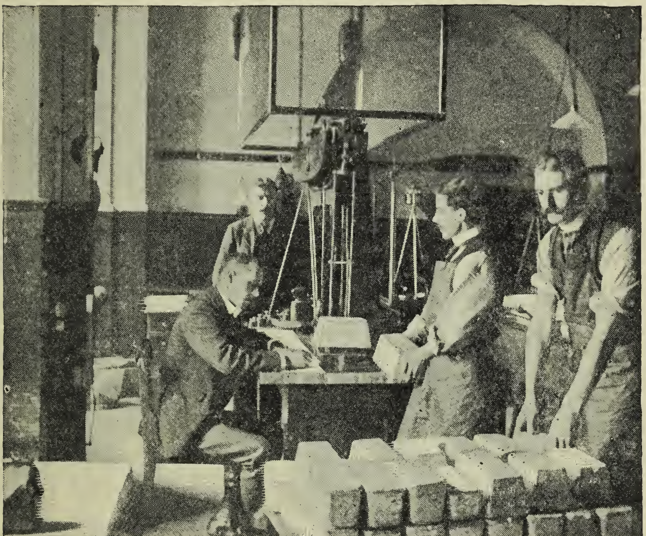


Fig. 1.—Weighing and checking Copper and Silver Ingots.
(Photo by Sturdee.)

silver in 100-lb. blocks. All gold coins are made of an alloy containing 22 parts of gold to 2 of copper; silver coins of an alloy of 37 parts of silver to 3 of copper; and for bronze coins a mixture of copper, tin, and zinc is used, bronze discs for the same being

occasionally manufactured in Birmingham. On rare occasions bronze has been coined by outside firms. Specimens can be recognized by the letter "H" which appears on the reverse below the date. But as it is

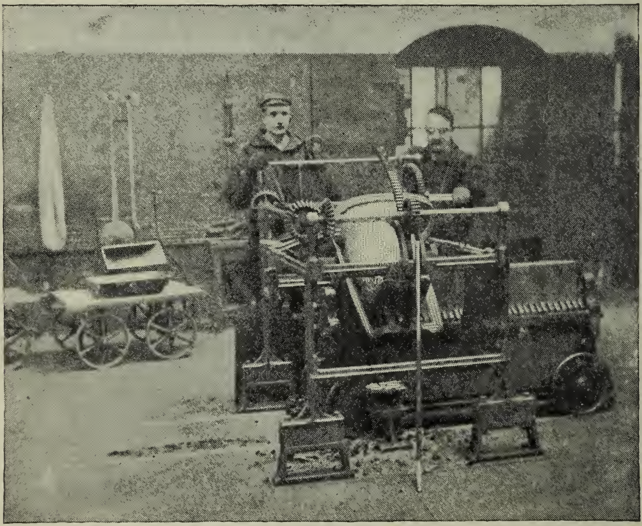


FIG. 2.—Casting Silver Bars.
(*Photo by Sturdee.*)

the stamping that converts metal into coin, the Mint may be considered responsible for all three coinages.

On either side of the office is a melting-room—one for silver, the other for gold. In the first a couple of men are extracting, by means of an electric crane, a large plumbago (blacklead) melting-pot from a hole

in the top of a furnace. It contains about 310 lbs. of molten silver. The crane brings the pot over a rack of moulds, which consists of a number of iron bars of H section clipped together by a screw-press, so that their edges make a tight joint. The pot is

Fig. 3.—The Gold Melting-house.

tipped up, and the moulds are filled in succession; and after a few minutes the fiery liquid has cooled into solid shining bars, which are easily separated from the moulds when the screw has been released.

In the gold kitchen there are eight furnaces to

heat as many crucibles, each containing about £5,000 worth of the precious metal. To-day is a busy one here, and the material for some 250,000 sovereigns is under treatment. The men stir the alloy very carefully to distribute the copper quite evenly among the gold. As the bars are taken from the moulds a bit is cut from the first and the last bar of each potful for testing purposes. (If the two samples have not the correct proportions of gold and copper, the bars are melted down again.) The rough edges are removed by a rapidly revolving cutter, and the bars are weighed and wheeled into

THE ROLLING-ROOM,

whither we will follow them. Here the bars ($\frac{1}{2}$-inch thick) are passed through several pairs of great steel rollers. In the first machine a bar is thinned by stages of $\frac{1}{100}$ of an inch. Then it goes through the other machines, which squeeze it into a ribbon or "fillet" about $1\frac{1}{2}$ inches wide and $\frac{1}{20}$ of an inch thick. The thickness is tested by a delicate gauge. It must be correct to within $\frac{1}{20000}$ of an inch; otherwise the coins stamped from the fillet would be too heavy or too light. It is sometimes necessary to pull the fillets between two immovable steel cylinders to give them

an even and due thickness. The machine used for this purpose is called a "draw-bench."

The next process—the first in the coin-making proper—is seen in

THE CUTTING-ROOM,

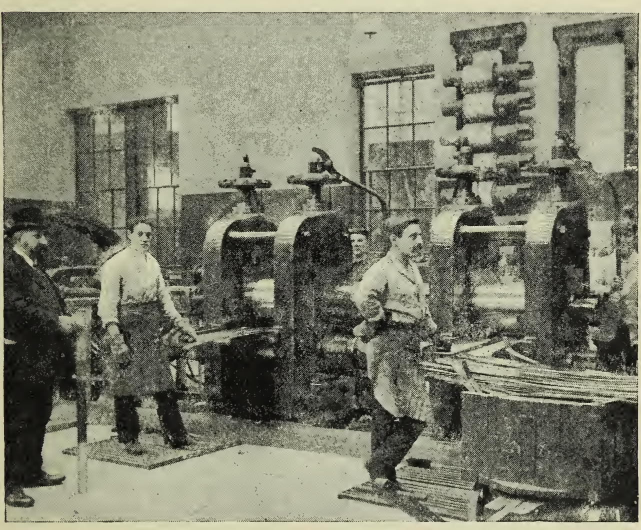


FIG. 4.—Rolling the Fillets.
(*Photo by Sturdee.*)

where we find powerful machines punching gold "blanks," two abreast, out of the fillets at the rate of about 150 blanks a minute. The "scissel," or metal left over (Fig. 5), is returned to the melting-house. The blanks have now to be "marked"—that is, have

their edges thickened to protect the device that will presently be impressed on the two sides. They are therefore passed rapidly between the face of a revolving grooved wheel and a fixed grooved block (Fig. 6), the distance between which is rather less than the diameter of the blank. Fig. 7 shows the blank before and after "marking."

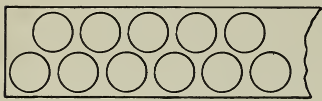


Fig. 5.

Before a design can be impressed on a blank it must be annealed or softened by heating. The gold blanks are placed in boxes of powdered charcoal, which travel very slowly through a furnace on an endless chain. The transit takes about three hours. After immersion in a bath of dilute sulphuric acid, they are cleaned by being rolled in beechwood sawdust, and passed on to

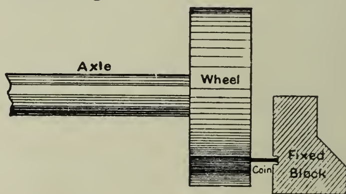


Fig. 6.—"Marking" Blanks.

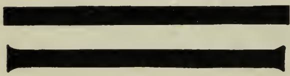


Fig. 7.

THE COINING-PRESSES.

The coining-press room is by far the noisiest place in the Mint. One cannot wonder at this, considering

that twenty presses are each stamping the King's portrait on ninety blanks a minute, and that each blank receives a 30-ton blow.

There are two dies in each machine, one fixed in

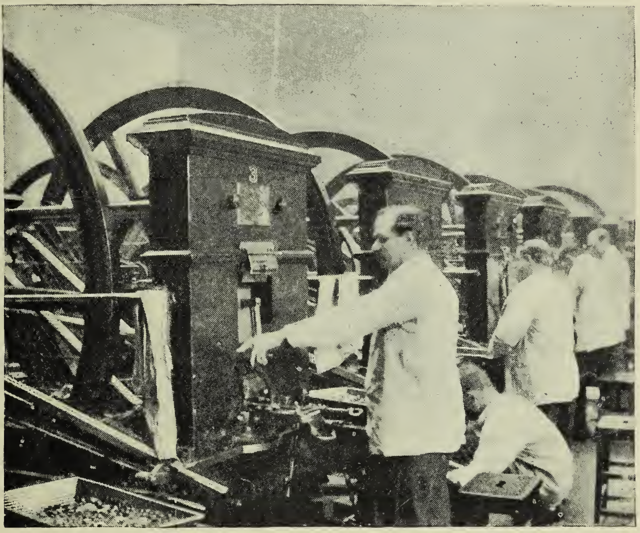


FIG. 8.--The Coining-presses.
(*Photo by Sturdee.*)

the bed, the other in a socket at the end of a lever immediately above. Between the two dies is another lever carrying a collar, the inside of which is serrated, or "milled," in the case of gold coins and all silver coins except the crown and threepenny-bit. An

automatic arm pushes a blank on to the lower die. The collar descends, encircling it. Then down comes the upper die with tremendous force, squeezing the surfaces of the blank into its own design and that of the lower die, and forcing the edge sideways into the fluting of the collar. The next moment it rises, followed by the collar, leaving the (now) coin to be pushed down a shoot by the succeeding blank. In one day a machine can coin about 40,000 blanks.

THE WEIGHING-ROOM.

The coins are now finished, but before being issued to the public they must undergo two tests—(1) for weight, (2) for soundness.

Weighing is done in one of a number of very delicate automatic balances, enclosed in glass cases, which are the most interesting machines in the Mint. We must digress here a little to say that the standard weight of a sovereign is 123·27447 grains, and that no sovereign is put into circulation which is ·17 grain heavier or lighter than this standard.

The weighing-machines are rather complicated, and in order to give the reader an idea of the *principle* on which they work, a very simple diagram (Fig. 9) is appended. From one end of the balance-

beam hangs a stirrup containing a counterpoise W of the standard weight. At the other end is a scale-pan, on to which the coins are pushed in succession. This pan is connected by a rod to arm A, sharply pointed at the free extremity.

Close to the pan is a funnel F, which swings on pivot P, and has on the inner side a projection N,

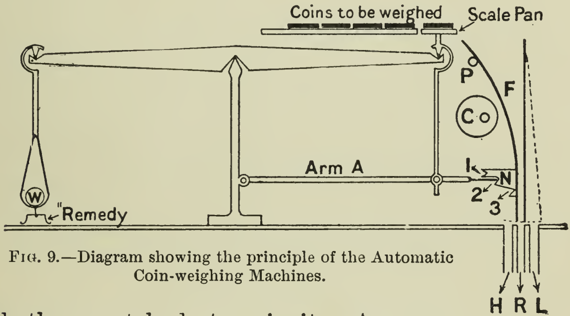


Fig. 9.—Diagram showing the principle of the Automatic Coin-weighing Machines.

with three notched steps in it. An eccentric cam C, revolved by an electric motor, pushes the funnel outwards at every revolution.

Below the funnel are three slots—H, for heavy coins; R, for coins of the right weight; and L, for light coins. A sovereign is shoved on to the scale-pan by the one behind. The cam pushes the funnel to the right, and holds it away for about three seconds. Meanwhile the coin has been finding its level. If heavier than the standard, it sinks; but if

less than ·17 of a grain too heavy, the scale-pan will not raise the "remedy," a tiny piece of gold wire weighing ·17 grain. So that when the cam allows F to return to the left, the arm A will engage with notch 2 in N, and the funnel be arrested over slot R, down which the coin falls when pushed off by its successor. Should the coin exceed the "limit of error," the arm A would sink lower and engage notch 3; or if it were too light, A would rise and catch in notch 1. Put briefly, the travel of the funnel towards the left and the destination of the coin depend on the weight of the coin.*

The second test is made by a boy, who picks up by the handful the coins which have passed the weighing test, and drops them smartly one after another on a steel slab. A cracked coin "rings" badly, and is placed on one side to be melted down.

Finally, the coins are "overlooked" on a contrivance by means of which both sides are exposed to view successively.

The sovereigns that pass the test are put up in

* The *Encyclopædia Britannica* says: "In order to show the importance of extreme accuracy in weighing, it may be pointed out that......in a million sterling of sovereigns the difference between the least and the greatest weight the law allows (·4 grain) would be no less than £3,244."

bags of one thousand, and returned to the office from which they came as ingots.

The counting of silver and bronze coins is done by a very ingenious automatic machine. The coins slide

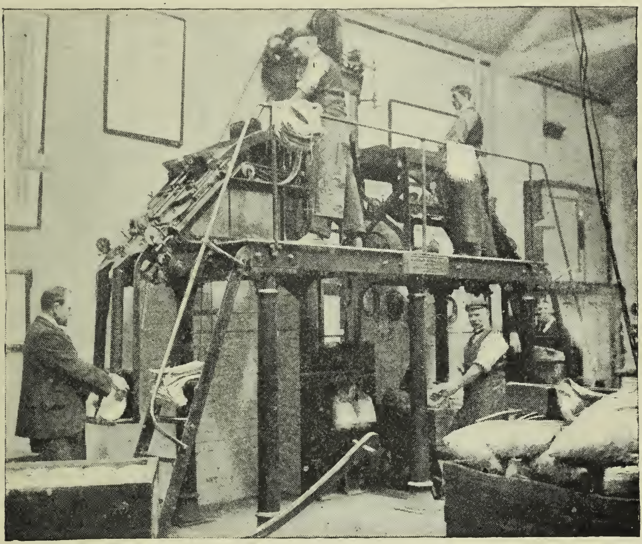


Fig. 10.—The Automatic Counting-machine.
(*Photo by Sturdee.*)

down a shoot which is partly blocked by the teeth of a wheel geared to the counting index. In order to get past, a coin must move a tooth on; the action being very similar to a cycle chain running over a chain-wheel, coins representing the chain rollers.

It has been calculated that a sovereign while in circulation loses $\frac{29}{1000}$ of a grain per annum, and a half-sovereign, which has much more handling, $\frac{42}{1000}$ of a grain. When three whole grains of gold have been worn off, a sovereign is "garbled"—that is, retained and sent back to the Mint—by the Bank of England.

MEDAL-MAKING.

Two rooms of the Mint are devoted to medals. The designs on these stand out much more boldly than those on coins, and the method of stamping just described would not be practicable for them. Every medal receives three blows from a large screw-press, and between two blows has to be annealed, cleaned, and polished. Its manufacture is therefore a comparatively slow business, though fast as compared with the making of a Great Seal of England, which requires two hundred blows.

The manner in which a die is prepared, for coin or medal work, is interesting. The artist first executes a large model, a foot or more in diameter, in wax. From this a mould is made, and from the mould a plaster cast. On this the medallist perfects his design. A steel cast is made from this, and from that a smaller cast of the size of the coin or medal is

copied by means of a machine. This final mould is called the "matrix." From it a "positive" die (one with the design standing out in relief as in the coin) is obtained by enormous pressure in a hydraulic press, and this in turn is similarly used to obtain the sunk dies for the coining-presses. A sunk die is not replaced until it is considered unfit for further use. A very good return for one die is 100,000 pieces.

A POPULAR FALLACY.

A number of people—the writer was once one of them—believe that pence struck in 1864 are especially valuable. A legend exists to the effect that some gold got mixed with the bronze used that year; but like a good many legends, it has no truth to support it. Let us see what the "Report of the Deputy-Master of the Mint" for 1904 says:—"It may be well here to correct an erroneous idea which is entertained by some of the public, that pence of various years—those of 1864 are generally mentioned—possess a greatly enhanced value, and are received by the Mint and paid for at various extraordinary rates, the amount which was last quoted by a correspondent being no less than £7, 11s. 4d. each! The present scarcity of pence of the year 1864 lies

in the fact that a very much smaller number of pence than usual were coined in that year, and they are in consequence seldom seen in circulation. It is perhaps hardly necessary to add that no pence are purchased by the Mint at either their nominal or at any fictitious value."

Chapter II.

HOW PAPER IS MADE.

The constituents of paper—Wood pulp—A Kentish paper-mill—Preparing rags—Boiling esparto grass—Breaking the grass—The *presse-pâte* machine—Beating and mixing—Colouring—The paper-making machine—Water-marking—Drying—Calendering—A long roll of paper—Rate of production—Finishing art papers—Drying—Cutting—Sorting—Automatic stokers.

PAPER-MAKING is one of the most interesting of all manufactures, because, in the first place, its processes are so ingenious; and secondly, because some of the materials used are in appearance so utterly unlike the finished product.

The main element of paper is the fibrous matter of certain vegetable substances—notably cotton, esparto grass, and wood. Most people have a dim idea that rags are used for paper, but comparatively few would suspect pinewood, and probably very few indeed have ever heard of esparto grass.

Now, the quality of the paper depends very much upon the thing or things out of which the paper is

manufactured. Drawing and other very high-class papers are made from rags. The *Times* is printed on esparto paper. This is tough enough to enable you to wrap up a pair of boots white tightly in a sheet of the *Times* without splitting it. The paper of cheap newspapers once grew as pine trees in the forests of Canada or Scandinavia.

Whether it be wood, grass, or rags, the substance contains a considerable proportion of matter which must be removed; and the useful remainder then has to be minced up and pounded and bleached before it is fit for the paper-making machine.

The first stage in the preparation of wood is done in the country where the timber grows. Logs are cut up into cubes of the size of lump sugar, which are crushed by powerful rollers and boiled by high-pressure steam for several hours in a solution of soda or sulphurous acid. The chemical dissolves the resinous, mineral, and other useless constituents, but only softens the tough vegetable fibres.

The "pulp" is mashed and made into what looks like sheets of light-brown cardboard, and is sent to the paper-mill in that form.

A mill which I visited in Kent handles all three kinds of materials in the manufacture of many

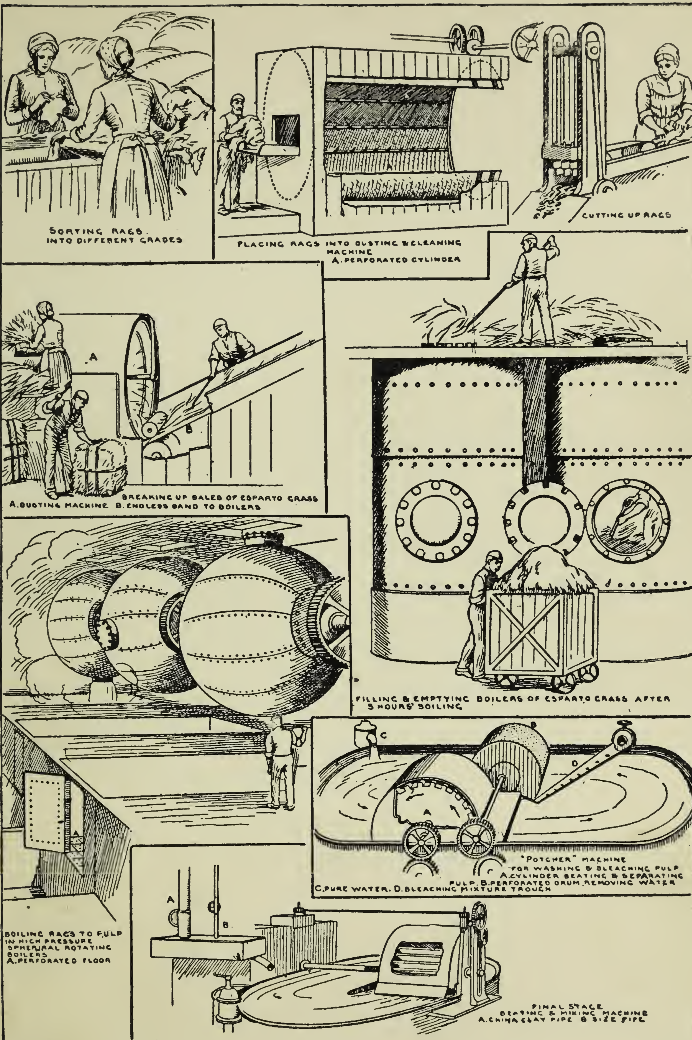


Fig. 11.—Diagrams illustrating the preparation of Rags and Esparto Grass for Paper-making.

~~varieties of paper. Let me now try to record what~~ I saw ~~there.~~

In the first room a number of women were hard at work sorting out linen and cotton rags, throwing them down on a metal slab to detect the presence of buttons—for buttons are as much out of place in paper as in a sausage. The sorted rags passed through a dusting-machine, and were then cut up into small pieces, preparatory to undergoing much the same process as the wood cubes. We will not linger over this, but pass on to a large barn full of what appear to be trusses of hay, but are really bundles of esparto grass—many thousands of them. The grass is imported from Spain and North Africa. The stalks, or rather leaves, are hard, polished, tough, and altogether most unsuggestive of paper.

Close by the store stands a row of great boilers, each capable of holding about three tons of the grass. The esparto (after being dusted and sorted) is thrust in through a manhole at the top of the boiler, and the lid of the manhole is screwed down tight. Valves are opened to admit steam and a solution of caustic soda, in which the grass stews for six hours. Then the "lye" is drawn off, and the now quite soft fibrous

matter is extracted and transported by a hydraulic lift to the "potchers" on the floor above.

A "potcher" is a very large oval tub, having a division running part way down the middle (see Fig. 12). At one side of the division is a casing, in which revolves a drum with knives set round the outside. These moving knives almost touch some

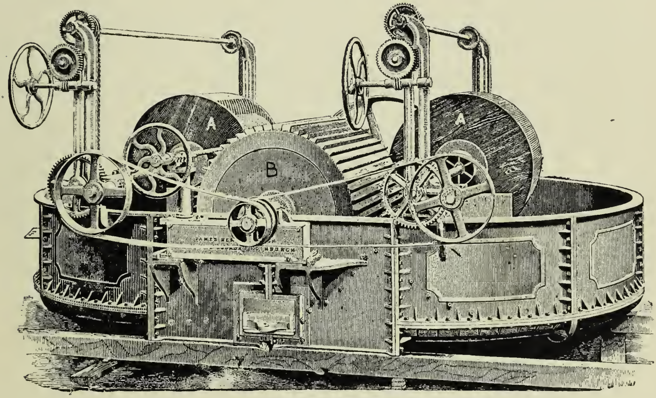


FIG. 12.—A "Potcher."—A A are revolving drums of fine brass wire-netting, by which the dirty water is removed. B is the knife-drum which breaks up the material—grass, rags, etc.

fixed knives attached to the bottom of the tub; in fact, the arrangement of the cutters is practically the same as that in a lawn-mower.*

Into the potcher is put a quantity of soft esparto fibre and water. The drum is started, and drives

* Some potchers have knives on the drum only.

the mixture round and round, chopping the esparto into very small pieces, till it looks like brown curds. At the end of two hours the man in charge adds some chloride of lime to the vat, and in a very short time the mass turns a creamy-white colour. The bleaching agent is then washed out by copious streams of water, and the pulp is passed into a big tank, called an "agitating tank" on account of a big vertical paddle which revolves inside it to prevent the solid part of the pulp from settling at the bottom.

From the tank the pulp-water is pumped up into the "sand-traps," a series of wooden troughs arranged like a maze, to catch any rubbish, such as stalks or dust, that may be present, and so arrives at the filters of the "half-stuff machine," otherwise known as a *presse-pâte* (paste press) machine, which drains off most of the water, and delivers the esparto pulp in thin blankets. These blankets are folded up and carried to the "beater."

The *presse-pâte* is a very ingenious machine, but as it much resembles the "wet-end" of a paper-making machine proper—to be described presently—a full description of it need not be given here.

Wood-pulp sheets are disintegrated and bleached in

just the same manner as the esparto, but afterwards the contents of the potcher are run into settling-tanks for the water to drain away. The solid pulp is then dug out into trucks, which transfer it to the "beater." There is no *presse-pâte* process for wood pulp.

We may imagine that the rag, esparto, and wood pulps have now reached the "beater" stage. Whether they will be mixed together in the beater or not depends upon what quality of paper is required. Sometimes rag and esparto pulps are blended, sometimes esparto and wood, sometimes all three, and again, sometimes each is used separately.

But in any case the pulp has certain ingredients added to it in the beater, which is a very close copy of the "potcher" in shape and construction. These ingredients are china clay, size, and resin, and their office is to render paper non-absorbent and soft.

The mixture is flogged by the beater for from eight to ten hours, according to quality. It requires great skill and experience to tell when the process has been carried far enough, and the excellence of the paper depends largely upon a thorough beating. Before the pulp is drawn off a little colouring matter—blue, red, or pink—is added, to counteract

any undue tinge, and produce a pure white. Here again discretion must be exercised, for sometimes the $\frac{1}{32}$ of an ounce of pigment suffices for 340 lbs. of solid pulp; but yet that tiny quantity must not be omitted.

Fig. 13.—View of a Beater Room.
(*Photo by Ramell.*)

The beating finished, the pulp descends to an agitating tank, from which it is pumped to the "wet-end" of the paper-making machine (Fig. 14). The chief feature of the "wet-end" is an endless belt, five or six feet broad, of very fine brass wire

gauze moving horizontally over a number of rollers. Along with it travels on each side a "deckle strap" of thick rubber.

The pulp passes through a very narrow slit in a vertical barrier called the "slice," regulating the

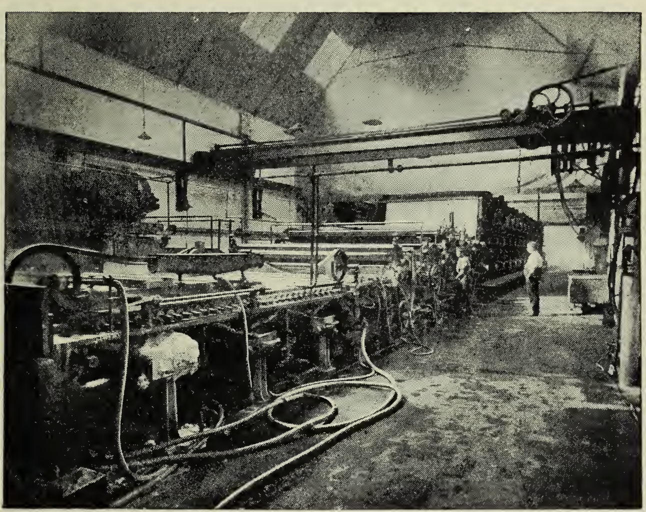


Fig. 14.—"Wet end" of Paper-making Machine.
(Photo by Ramell.)

thickness of the paper, on to an apron, which guides it to the wire gauze belt. This is shaken vigorously from side to side by machinery to distribute the pulp evenly, and the deckle straps prevent any pulp from running off at the edges. The breadth of the paper,

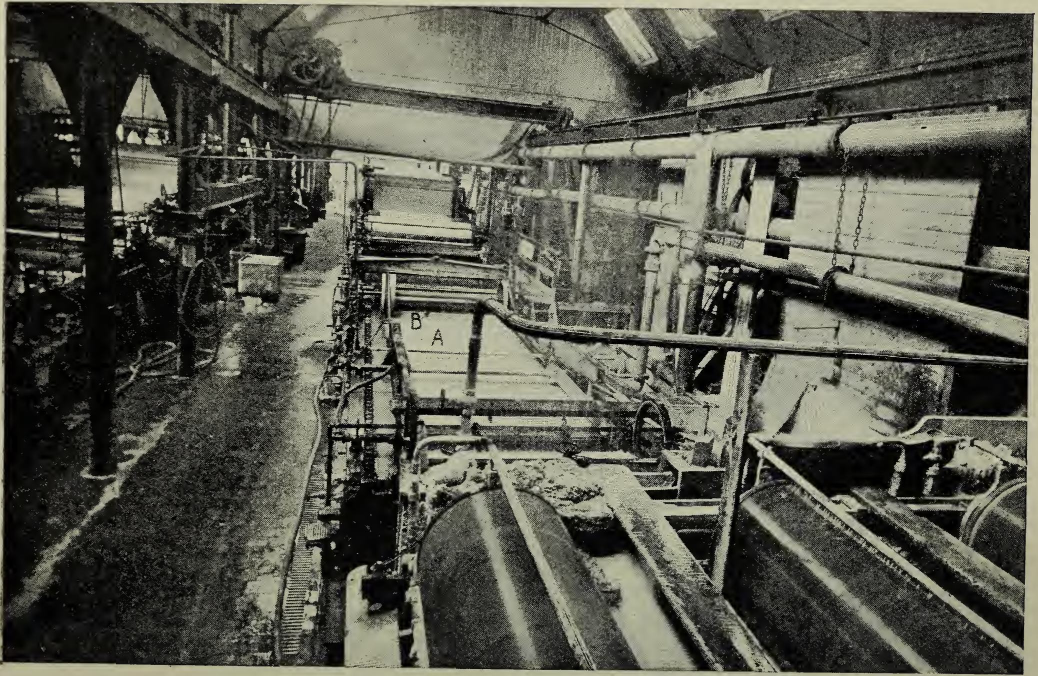


FIG. 15.—Another view of the "wet end" of a Paper-making Machine.—A is the sheet of half-drained pulp, passing on to B, the "dandy" roller.

by-the-bye, is decided by the distance between these straps.

Almost in a moment so much water drains through the wire that the pulp solidifies under our eyes. But gravitation alone would not extract the water efficiently. At the farther extremity of the "wet-end" are two *suction-boxes* underneath and touching the belt. The air is constantly sucked from these by pumps, and the fresh air rushing in to fill the vacuum is obliged to pass through the pulp, and takes a large part of the remaining water with it. A roller, called the "dandy" roller, is situated above the belt between the suction-boxes. It may be made of plain wire gauze, in which case all the half-dried pulp that passes under it will be impressed merely with the pattern of the mesh, and produce a "wove" paper such as this book is printed on. Or it may have thick parallel wire ribs running round it at intervals, and thinner wires set closer together running from end to end. This patterns the paper as shown in Fig 17, making it "laid." If the thinner wires run circumferentially like the ribs, you have a "spiral laid" paper. In addition there

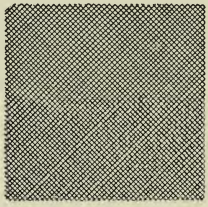


Fig. 16.—"Wove" Pattern.

may be an elaborate raised design or words in wire, to make the *water-mark.* The effect of the "dandy" is that some parts of the pulp get a harder squeeze than the rest. Wherever the wire touches the pulp, the pulp becomes thinner and more transparent, and so a pattern is produced, which you may see by holding the paper up to the light.

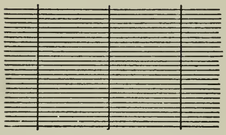


FIG. 17.—Part of "dandy" roller for making a "laid" paper. The three thick lines are wires running round the roller over the longitudinal wires.

The suction-boxes passed, the pulp encounters the felt-covered "couch" roller, which gives it a good wringing, and then two bright brass rollers in succession. After leaving the second of these it is sufficiently consolidated to merit the name of paper. But its travels are as yet mostly before it, for it has to pass round the outside of sixteen or more great polished drums, forty inches in diameter, heated internally by steam. These gradually rob it of its moisture, and so prepare it for being pressed by several pairs of very hot rollers, named calenders, which put a gloss on it. Finally, it is wound off at the "dry-end" on to great reels, holding from a half to two tons of paper. The longest continuous roll of paper ever made in this particular mill

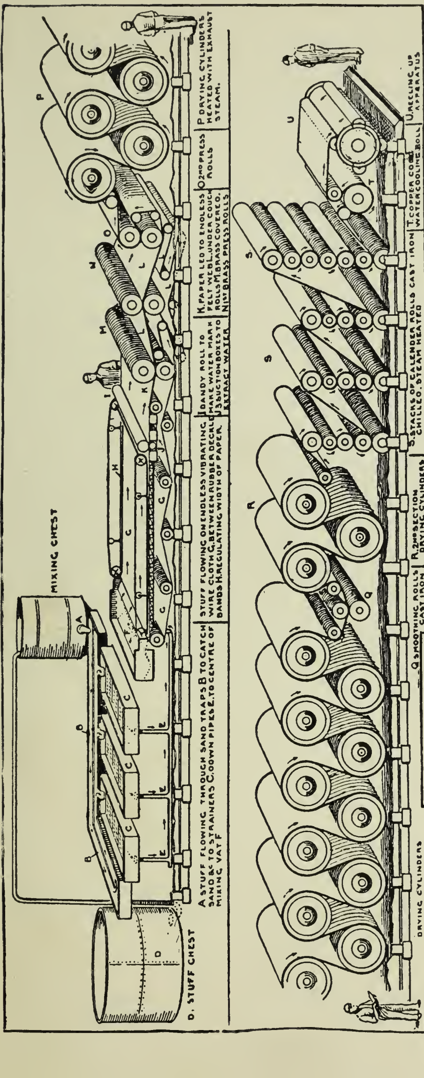


Fig. 18.—General view of Paper-making Machine.

measured nine and three-quarter miles, and was exported to an exhibition in Australia.

The speed at which paper is turned out by a machine depends largely upon the quality. For fine writing-papers it may be set down at from 60 to 90 feet per minute; but for newspapers a rate of 400 feet is sometimes attained. The width may vary between 5 and 12 feet,

and the thickness range from one to eleven units. Thus, the same machine can turn out paper varying from 11 lbs. to 110 lbs. to the ream (= 480 sheets) of demy size, $17\frac{3}{4} \times 22\frac{1}{2}$ inches. A large machine has an output of 70 tons a week when making inferior kinds of paper.

Some papers go straight from the machine to the printer, but those of the "art" grade, which require a very fine finish, are taken to a special coating department. The paper is unwound from the reel through a trough filled with a white liquid mixture, which two brushes, moving vigorously to and fro, distribute evenly over the surface as it emerges. A long arm, thrust automatically under the paper, gathers up a big loop, and as soon as the loop is complete a rod catches the loop, and the arm sinks to gather the next one. The rod is mechanically transferred with its load to a couple of endless chains running on raised tracks in the drying-room. We see dozens of these festoons of snowy paper journeying slowly along to the end of this room, rounding the corner of the track, and returning to a reeling-machine, which winds them off and sets the rods free for further duty.

The paper is next passed once or twice, as the

case may need, through a steam-heated calender. The starching and ironing have made the surface smooth and glossy, and capable of reproducing clearly the finest lines that may be printed on it. The paper

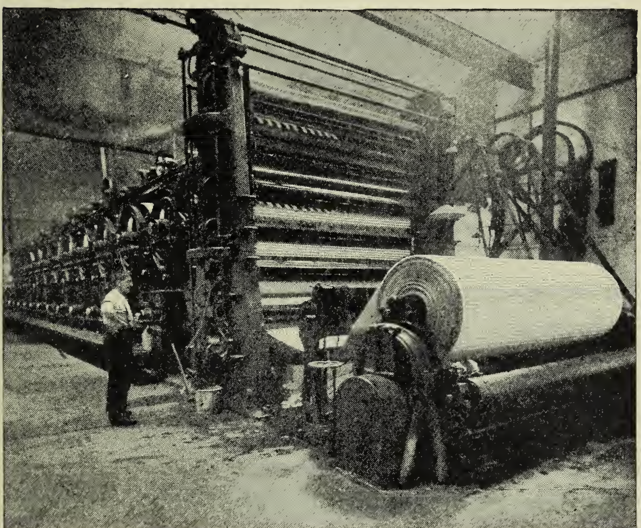


FIG. 19.—The "dry end" of a Paper-making Machine.
(*Photo by Ramell.*)

that was being coated at the time of my visit was destined for *Country Life*, a journal distinguished by the excellence of its illustrations.

Sometimes, one may say generally, this class of paper is cut up into sheets at the mill by a rapidly-

revolving knife, which flings sheet after sheet on to a table, whence a boy gathers them into neat piles.

However carefully the colouring and coating ingredients may be mixed, one batch of paper may

FIG. 20.—The Reeling-room.
(*Photo by Ramell.*)

differ slightly in tone from another. So before they go to the packer the sheets are sorted according to tint by girls whose trained eyes detect the slightest colour variation.

The packing department contains a hydraulic press,

which squeezes a bale very tightly while men encircle it with strip iron.

Other interesting machines on the premises are the huge steam-engines of from 300 to 500 horse-power, which make the wheels of the factory go round; and the automatic stokers, which feed coal from hoppers into the glowing furnaces of the boiler-house. The man in charge has only to fill up the hoppers now and then, instead of being constantly obliged to open the furnace door and face the scorching heat while shovelling in more fuel.

[*Note.*—The photographs illustrating this chapter were taken in Messrs. Edward Lloyd's Paper Mills, Sittingbourne, Kent, by Mr. F. M. Ramell.]

Chapter III.

HOW MATCHES ARE MADE.

The cheap and ubiquitous match—Messrs. Bryant and May's factory—Square wood matches—Making the heading composition—Reeling the splints—Dipping—Unreeling—Boxing—Round wood vestas—A wonderful machine—How it works—Making card-board boxes—Wax vestas—Making the "taper"—Cutting it up—Heading wax vestas—A huge output.

A FEW centuries ago, if you had produced a little piece of wood and, by rubbing it lightly against a little box, had caused the end to ignite suddenly, you might have run some risk of being yourself set on fire as a professor of the black art. If, however, you could have persuaded people to view the matter differently, and you had possessed a few dozen gross of boxes, a large fortune would have been at your command.

To-day the man is poor indeed who cannot afford a box of the useful little fire-sticks that are among the cheapest of the cheap things which we buy. For twopence-halfpenny you get twelve boxes. Each box

contains about fifty matches, so that two hundred and forty matches a penny is the rate.

For matches to be so cheap their manufacture must be conducted very economically. You cannot imagine even a Chinese workman being able to split and dip separate matches and sell them profitably at their present price. He could not possibly compete with the machine of the white man, who strews matches so plentifully wherever he goes.

In this chapter I want to tell you of the famous works of Messrs. Bryant and May at Bow in the East End of London. These works are all the more interesting because there you may see the most modern methods in operation side by side with methods which, though extremely ingenious, they are gradually supplanting.

Under the kindly guidance of one of the directors, I was shown how three different types of matches are made: (1) the square wood match; (2) the round wood match; and (3) the round wax match, or vesta—all three of which you use yourself.

The first process I saw was the mixing of the igniting composition used for "heading" the matches in large mills, through which it is passed twice. Then we entered a room where machinery whirred,

and workpeople were busy preparing square wood splints for dipping. These splints, by-the-bye, all come ready-made from Canada, where whole forests are converted into matchwood by very clever cutting machinery.

THE SQUARE MATCH.

If I were to let you have many tries, I wonder whether you would guess correctly how these splints are arranged quickly in groups in such a manner that no two splints may touch when ready for dipping. Well, this is how it is done. A long canvas belt, passing under a hopper full of splints four inches long, is wound on to a revolving reel. The splints fall on to the belt one after the other in quick succession, are spaced out, and drawn in between the layers of the belt, which, when fully wound, makes a coil about 18 inches in diameter containing four thousand splints. The splints being an inch or so longer than the belt is wide, their ends project like a multitude of bristles on either side of the coil. From the winding-machine the coils go to the "beater," a circular press which levels the ends of the splints. Then they are drawn over hot iron plates to heat and dry the ends, which are subsequently immersed in a bath of liquid paraffin wax. This substance renders the wood near the heads

very inflammable. Down a lift travel the paraffined splints to the dipping-room. The heading composition is spread out on steam-heated slabs by a horizontal knife or gauge working in a frame. The dipper moves this knife across his slab, scraping aside all the stuff except a layer of exactly the right depth, takes a coil, dips one side into the composition, hands it to a boy to hang up to dry, ready for dipping on the other side; scrapes again, dips the next coil, and so on all through his working day, by the end of which he will have put the heads on some fourteen million matches!

The coils of matches are placed in rooms in which warm air is kept in circulation by means of revolving fans; and as soon as the heads of both ends are dry, the coils pass to the unrolling department. The belt is unwound, and as the matches fly out they are caught in trays and given to deft-handed women, who seize exactly the right number to fill a box, cut them in half in a guillotine, and press them into their box. The actions are repeated so fast that one can hardly watch the nimble fingers. The full boxes are done up in packets, the packets in cases, and the matches are ready for the public.

All this is very wonderful, but there are better things to come in the round match department.

MAKING WOOD VESTAS.

The first thing one sees on entering this department is a maze of big drums slowly revolving. Looking closer, you notice that the drums are arranged in sets,

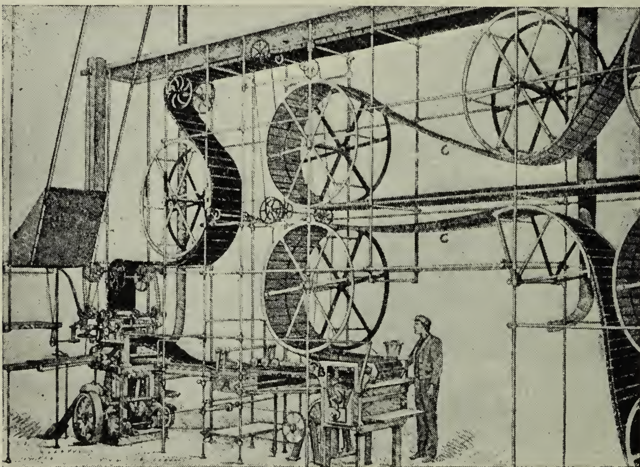


Fig. 21.—Machine for making round wood vestas.—A is the paraffining tank; B, the "heading" tank; C, the belt of iron links carrying the matches in rows over big drums to dry them.

one set to a machine about 63 feet long, 2 feet wide, and 15 feet high; further, that over these drums travels a continuous chain of metal plates with myriads of matches projecting from one side of it.

At one end of the machine a girl is feeding long

blocks of pinewood into two guides, at the bottom of which is a travelling belt. This carries them forward into the grip of two fluted rollers, which present the ends obliquely to a row of forty-eight cutters. Each cutter is a small steel bar of rectangular section with an almost circular projection at one end, through which is drilled a hole of the size of the match. The metal round the hole is very thin, and sharpened at the lower edge. Down come the cutters through the wood. When they reach the end of their stroke a plate studded with little steel pegs rises under the cutters, keeps them company during the up-stroke, and then helps to push the splints out of them into a row of holes in the travelling chain, which has halted for a moment. The holes in the chain being a trifle smaller than the holes in the cutter, the grip at the chain end is tighter than at the cutter end, and all the splints are withdrawn from the cutters. This operation is repeated two hundred and sixty times a minute for ten hours, so that the machine turns out about seven millions of matches a day, allowing for stoppages and "broken sticks."

Let us watch the progress of the splint after it enters the chain. As it passes slowly forwards the lower end is drawn through a bath of melted paraffin

wax, kept at a constant level by a little automatic bucket that ladles wax in from a reservoir beneath, into which the surplus constantly overflows. After emerging, the splint travels a little way through the air to allow the wax to set, and next encounters a roller turning in a bath of igniting composition. The roller picks up a layer of the proper thickness for the head, and, since its circumference moves at the same rate as the belt, the match is not *dragged* through the composition, but is gradually submerged and drawn out. The effect is the same as a vertical dip, and gives a perfect pear-shaped head.

The matches are now complete, and have only to be dried by travelling over a large number of the drums already mentioned. At the end of an hour or so they have returned to the head of the machine, where they are ejected from the belt by a row of punches, and automatically thrust into the trays of boxes which have been moved underneath by a travelling belt. This belt ejects the trays filled with matches on to a circular revolving table. Girls seize the trays, thrust each into a cover, and drop the now completed boxes on to the table. Another girl slides them down a shoot to the packers, who snatch up twelve boxes at a time and pack them up in a printed wrapper, and

then twelve packets into a larger parcel, to make a gross of boxes. The grosses are consigned to wooden cases, and the business is complete.

Messrs. Bryant and May are now introducing a

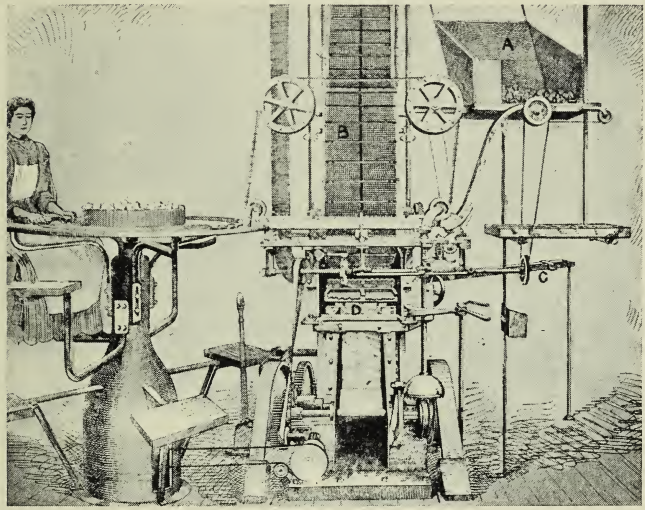


FIG. 22.—The "head" of a Wood Vesta Machine.—A is a hopper full of box trays; B, the belt carrying matches; C, the channel through which wood blocks are fed to the knives in D to be cut up into round splints.

machine for making square matches by the same process.

A BOX-MAKING MACHINE.

In the same room is a wonderful machine forming box covers (the cover is the outside or case of the box)

out of a long ribbon of cardboard. The mechanism scores the strip longitudinally in four places where the bends will come, glues one edge, doubles it so as to form a continuous rectangular tube, prints any

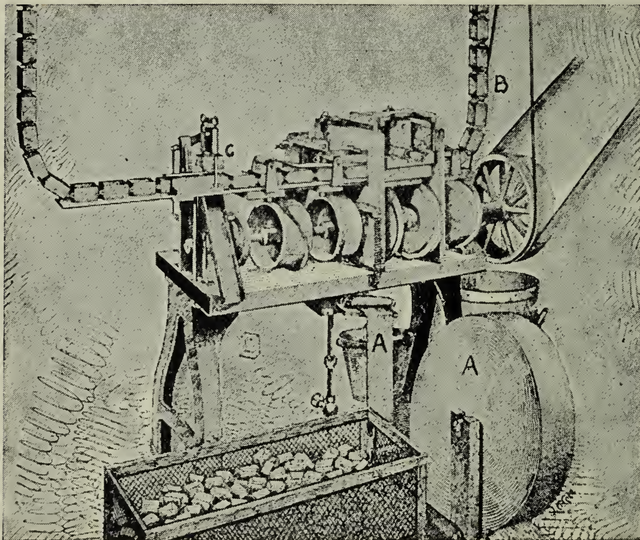


Fig. 23.—Tray-making Machine.—A is a roll of cardboard strip; B, a belt of metal "formers;" C, the die which bends cardboard sheet into shape.

required design on the top and bottom, glues one side and sprinkles it with ground glass to make the "striking" face, and chops the tube up into covers, which are delivered at the rate of about eight hundred per minute.

Another machine (Fig. 23) makes the trays. In Fig. 24 you see part of a cardboard strip, the shaded portion of which represents the material used in one tray. At each end is part of an adjacent tray, unshaded. Sharp wheels score the cardboard lengthways and across along the dotted lines. Up comes an arm with twelve projections on it, each loaded

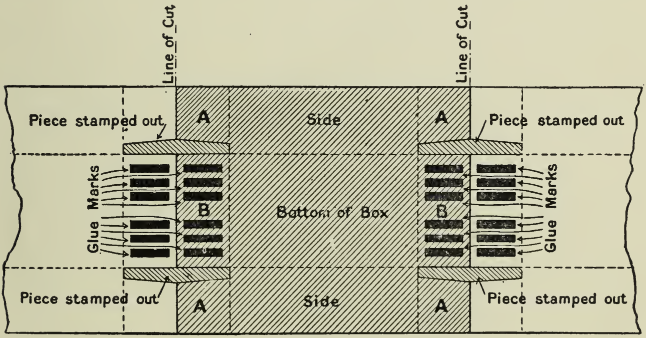


Fig. 24.

with glue, and makes a dozen patches on the card (marked in solid black). These patches are equally distributed between the ends of two neighbouring trays, so that two "dabs" are required for each tray. Next, the pieces shaded with lines running from north-west to south-east are stamped out to give room for bending, and the strip is severed down the "line of cut." Each piece is brought under a die, which bends

the ends A A at right angles to the sides, and turns the sides up square to the bottom. Then the ends B B are raised and pressed tightly against A A, to which glue makes them adhere. The complete tray is forced into a metal "former" fixed to a band, in which it travels for one revolution of the band, that the glue may set. Finally, a punch presses the tray out of its former, and it slides down a shoot into a large basket.

But we must pass on to the wax vestas.

THE MAKING OF WAX VESTAS.

Take a vesta, knock off the head, wrap it up in a bit of blotting-paper and hold it near the fire. The wax melts and is absorbed by the paper, leaving a number of bare cotton strands. In a vesta that I have just treated thus there are twenty-one of these strands, each composed of many cotton threads twisted together.

In one part of the factory stand a number of bales of cotton yarn. My guide rips open the canvas case of one of these and reveals what appears at first sight to be a tangled mass. After a little search an end is found, and the tangle resolves itself into a rope of threads. This rope is $1\frac{1}{2}$ miles long, and the strands are divided up into fifty groups by passing through holes in a flannel end-piece.

When the cotton has to be coated to form "taper" for matches, the bale is removed to the dipping-room. Operatives attach the extremities of two ropes to a huge drum or reel at one end of the chamber, and wind on the ropes, which, as they pay out, are grouped by the end-piece referred to. When all is on, the free ends of the groups are passed through the interstices of what may be called a very small fence standing on the edge of a tank, under a roller which nearly touches the bottom, through one hundred holes in a steel die on the other side, and away to another big reel.

The tank is filled with a mixture of glue and stearine, kept liquid by steam circulating in a jacket enclosing the tank. Reel No. 2 is revolved by an engine, and gradually robs reel No. 1 of its one hundred groups of threads, each of which receives a coating of stearine. The steel die scrapes off all superfluous wax as the (now) taper passes through. This process is repeated several times, the reels being alternately wound and unwound, and the die shifted from one side of the roller to the other. The temperature of the stearine bath is lowered between every two windings; and at last we have 150 miles of beautifully smooth cylindrical "taper" on one reel.

This is transferred to the match-making room,

FIG. 25.—A Wax Taper-making Plant.—A is the trough of melted wax through which the cotton strands are drawn.

where it is cut up into the required lengths, dipped and dried, and, being now converted into wax vestas, packed in boxes by a machine very similar to that which makes round wood vestas, the points of difference being that a row of lancets replaces the steel cutters, and that the chain grips each wax stem after it has been cut off from the reel by means of a tiny spring, so as not to injure the substance.

A single reel of taper cuts up into about 9½ million wax vestas one inch long.

The total output of the factory is some 1,300 million matches a week. This is an enormous number, but yet it would not suffice to allow the inhabitants of the globe a single match all round per week; so Messrs. Bryant and May find plenty of work for another large factory in Liverpool, although there are other very productive firms in the kingdom, to say nothing of huge factories in foreign countries.

We might notice at some length the making of fusees; the machinery for carrying away fumes, dust, and chips from the workshops by induced draught; the ingenious lathes which peel a continuous thin wafer off a revolving log for box-making; but there are other manufactures demanding their share of our space, and we must "move on."

Chapter IV.

THE BUILDING OF A PIANO.

Handel and his spinet—The materials used in making a piano—Wood piles—Cutting and drying the wood—The joiners' shop—Veneering—A mechanical rubber—The sounding-board—The frame—Boring holes for the wrest-pins—Piano strings—The keyboard—Covering the hammers with felt—Polishing—Adjusting—Tuning—Factory organization.

A VERY pretty little story is told about the boyhood of Handel, the famous composer. Though born a musical genius, he was discouraged from the pursuit of what his father considered to be a contemptible art. But so strong was his passion for music that, with the aid of a kindly aunt, he managed to smuggle a spinet up into the attic. The instrument's feeble sounds were not noticed until one night his father heard strange noises issuing from the floor above. The search that ensued led to the discovery of seven-year-old Handel, clothed only in a nightgown, playing on his beloved spinet, without thought of the cold and darkness. From

that night may be said to date his glorious career as a musician.

This happened more than two hundred years ago. Since then the piano has been improved enormously in every respect. Even the cheapest "cottage" piano is vastly superior to the spinet of the story; and the imposing "grand," with its beautiful finish inside and out, and its full, rich tone, is a thing that Handel could only have dreamed of.

Probably very few of the many people who play on pianos realize how great are the skill and care devoted to the manufacture of a high-class instrument. In order that the reader may regard this particular piece of furniture with increased respect, I have included a chapter on the factory of the well-known pianoforte makers, Messrs. John Broadwood and Sons, situated on the banks of the Lea River Canal in the East End of London.

The two main materials used in the construction of a piano are steel and wood—the first for the pins, wires, and, in some instances, the frame of the sounding-board; the second for the case, keys, and "works" generally. Several kinds of wood are required—pine, oak, beech, mahogany, American poplar, sequoia, rosewood, satinwood, and walnut, the three

last for veneering the case. On the wharf beside the canal are tall piles of timber, which remain exposed to wind, rain, and sun until they have been well seasoned. When any kind of wood is wanted by the workmen, it is transferred to a sawmill, where saws of different forms cut it into suitable sizes. The pieces are neatly stacked on trucks and pushed into drying-chambers, where they remain for six months, exposed to an average temperature of 140° F. The chambers resemble tunnels, long enough to accommodate several trucks. A truck enters at the cooler end, and is moved forward, like a cab on a "rank," whenever a load of wood is taken out at the exit end, near which the heated air enters.

When thoroughly dried in this manner, the wood is placed in a large store built in two floors above the drying-rooms, and remains there until its turn comes to be converted into some part of a piano. Then it undergoes further sawing, and passes through planers, whose knives, revolving some thousands of times a minute, whisk off all superfluous matter and leave a smooth surface. This is faced down by a machine which has a large whirling drum covered with sandpaper, against which the board is pressed by rollers.

There are some twelve thousand separate parts in a Broadwood "grand," many of them glued together in groups to form a larger part. We may first give our attention to the case. One side and one end of this and the cover of the keyboard have to be bent. This is done by steaming them and pressing them in wooden moulds.

The case is usually made of white wood, covered with a veneer of rosewood, mahogany, or walnut. In England the first stands foremost in popular favour, while walnut is preferred by Australians. The reader probably knows that veneering consists of gluing a very thin slice of valuable wood on the surface of a common wood. In the veneer store are piles of these thin sheets, which have been sliced lengthways off logs by parallel saws, or peeled off the circumference of a log turning in a lathe, the cutting tool of which approaches nearer to the centre at every revolution.

Many of the veneer sheets have holes in them. These are filled in by a skilled workman, who inserts pieces of the same veneer of equal tone and colour, and pastes glued paper slips over the joints—so cunningly made as to be almost invisible. He then glues the wood to be treated, lays the veneer on it,

and a sheet of hot zinc on the veneer, and places the whole in a press. When the first layer of veneer is thoroughly dry, a second is glued on to it across the grain, so that each may prevent the other curling away from the wood. The surface of the outer veneer then undergoes a good rubbing in a very ingenious machine, the chief feature of which is a belt of fine sandpaper running round a couple of pulleys, outside a belt of thin steel. The surface to be rubbed is moved backwards and forwards mechanically from north to south, as it were, and the attendant, by means of a lever, can press the belt (running from east to west) down at any point on to the veneer beneath. This is one of the two machines of the kind at work in England. If you rub your finger over the finished surface, it feels as smooth as a sheet of notepaper.

The most important large piece of woodwork in a piano is the sounding-board. In many ways this resembles the upper surface of a violin, but it differs in that it has to withstand the oblique strain, not of four light catgut strings, but of some two hundred odd steel wires. It must therefore be very strong. The most suitable material for its construction is Swiss fir, the familiar Christmas tree. A number

of boards of this wood, about 3 inches broad and $\frac{1}{4}$-inch thick, are glued together by their edges to form a large sheet. Upon the upper surface of the sounding-board are fixed the bridges over which the strings are stretched; and to the under side are

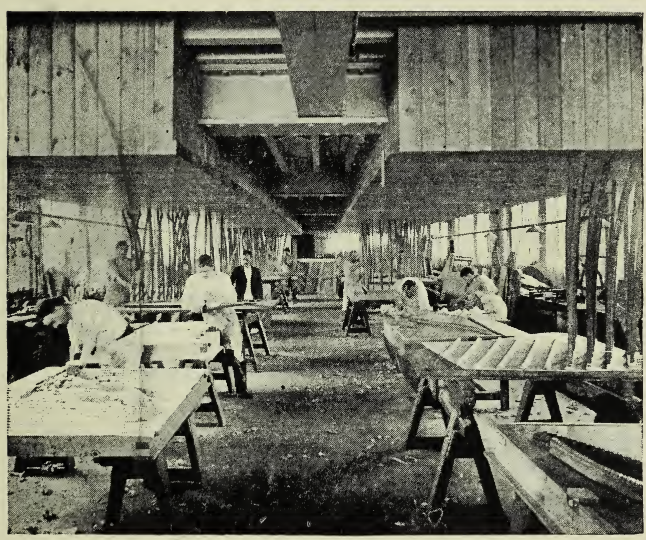


FIG. 26. – Making Sounding-boards.

glued a series of parallel ribs of wood, kept in position while drying by rows of sticks jammed between them and the ceiling (see Fig. 26).

When completed, the board is attached to the steel frame, shaped somewhat like a harp, which

bears the longitudinal pull of the strings, amounting to 30 tons in some pianos. A large "barless" frame weighs about five cwt. Along the edge nearest the keyboard a number of holes are bored for the wrest-pins—corresponding to the tuning-pegs in a violin—to pass through to the wrest-plank beneath, which is supported by the frame. In spite of a host of rival mechanical inventions, the tapering wrest-pin, with a square upper end to fit the tuner's key, still holds its own in pianoforte-making. But its efficiency depends entirely upon the care with which the holes for the pins are made in the wrest-plank. The workman uses no fewer than six boring tools of slightly different diameter, and decides by the feel of the wood which of the set he ought to select. If the plank is hard, he employs the largest drill; if soft, a smaller one, because the pin will expand the hole a trifle. A properly-fitted pin never slips, though the least pull it has to withstand is 300 lbs.

The strings are made of the finest quality of steel, calculated to bear a strain of about 150 tons on a bar one inch square in section. In proportion to its diameter, a piano wire is the strongest thing made by human hands, and if you range through all nature,

only certain kinds of spiders' web excel it in this respect.

Trichord pianos have three strings, tuned in unison, to each of the treble notes, and two or one to each of the bass notes. Strings of deep pitch are "spun" —that is, wrapped round with fine copper wire to increase their weight and reduce the rapidity of vibration.

The case of our piano having been completed, and provided with the sounding-board and strings, it is handed over to the finishers, who fit in the "action" —the technical name for the ivory keys, hammers, and their connecting mechanisms.

You may think that the keys are made separately; but this would be a very slow process, and render it rather difficult to get the keys of a uniform size. What actually happens is this. The workman planes a plank till it has the sectional shape of a white key, veneers the front and back edges, and after marking it off by transverse lines into as many divisions as there will be keys, cuts out the spaces for the black notes, and cuts it across along the marks. The keys are then entrusted to other workmen, who glue to their top surfaces thin slips of ivory bleached to perfect whiteness. Up to the

present time no satisfactory substitute for this costly material has been found, but hopes are entertained that a certain substance made from milk curds will prove efficient.

The covering of the hammer-heads with felt is

Fig. 27.—Making the Keyboard.

an operation which demands a great deal of practice. The felt must decrease in thickness from the bass to the treble end of the keyboard, and since on its due proportioning largely depends the tone of the instrument, a hammer-coverer has a very responsible task to perform. He works on the same principle

as the keymaker. The hammer-heads are made out of a tapering bar of wood, along one edge of which is glued a strip of felt, which also tapers from end to end, and from the centre towards the edges. This felt is very expensive, and requires

FIG. 28.—The finishing touches.

careful cutting. When the glue has set, the felt is divided up into hammer-heads by a knife.

The completely-assembled piano is polished by skilled workmen until its outer surfaces have a glass-like smoothness.

It now only remains to adjust the "action" perfectly and tune the strings. The first process is

effected by means of thin paper rings slipped over the pin which projects from the keyboard up into a slot near the outer end of the key. When the proper number of rings are on the pin, the hammer moved by the key will fall away from its strings the correct distance after striking.

The last stage of all, the tuning, requires the services of assistants whose ears have been educated by years of practice. Tuners are preferably drawn from choir schools at the age of fourteen, as the musical training previously received enables them to become efficient more quickly. The visitor, watching a tuner at work in a room where a number of pianos are being treated, wonders how he manages to concentrate his attention on the sounds of his own instrument.

From the tuner the piano goes to the showroom, where a specimen of exceptional magnificence may sometimes be seen. Hundreds of pounds are often spent on the ornamentation of a modern pianoforte after the designs of a prominent artist.

In describing the growth of an instrument in its passage through the works, it has been necessary to omit many of the branches of the trade, all of which are of interest by reason of the great variety of the

methods employed and the ability of the mechanics who carry them out. Few, if any, manufactures combine so many trades, all needful for the production of the finished article, as does the making of a piano. It is difficult, except by actual inspection, to realize what a number of hands the instrument passes through during its gradual conversion from the raw materials. The whole factory is arranged on carefully-planned lines, so that there may be no confusion or waste of time. The various parts of a piano are brought together just in the right place and at the right moment. It should here be mentioned that in addition to the numerous joinery shops are several devoted to the manufacture of small metal parts, such as springs, hinges, and rods.

The large quantities of sawdust, chips, and shavings necessarily produced in a large wood-working factory find a use here. They are drawn by air-suction through large pipes to the engine-room, where a fan flings them into the furnace of a boiler that raises part of the steam consumed by several powerful engines busily generating electric power for distribution over the works. In this manner is effected a great reduction of the annual coal-bill, while the workshops are kept free from accumulations of rubbish.

Chapter V.

CANDLES AND SOAP.

The importance of the candle—Early candles—Sperm and tallow—Chevreul's discovery—Stearine, oleine, and glycerine—Paraffin wax—Testing a candle—The preparation of stearine—Refining paraffin scale—The wick—Candle-moulding—The machine used—Self-fitting ends—Night lights—Soap—Its manufacture.

"THE game is not worth the candle" is a saying that dates from a time when a candle was more costly, more troublesome to make, and less efficient than it is to-day; and yet of much more importance as an illuminant, because oil and gas and electric lighting were still things of the future. In spite of the introduction and universal use of these last three, the candle still holds its own, partly because it has certain conveniences, and partly because improvements in manufacture have at once reduced its cost and increased its light-giving power.

The earliest candles were mere "dips," made by immersing a wick in a tank of liquid tallow or

other fat. Presently spermaceti, a wax found in considerable quantities in the skull of the sperm whale, was introduced. Sperm candles are beautifully white, and burn with a regular flame, on which account they have long been, and still are, used as the standard measure of artificial light—the standard candle being so prepared as to consume 120 grains of sperm per hour.

But both sperm and tallow candles had their disadvantages: the first were costly; the second "guttered," or melted so fast that a large part of the fat ran down the side and was wasted. It remained to find a substance at once cheap and slow melting. Chevreul, a French chemist, issued a book in 1823 to prove that fats were not simple substances, as had been previously supposed, but compounded of a mixture of *solid fatty acids* now called stearine, a liquid fatty acid (oleine), and glycerine. This discovery showed why tallow was so unsuitable for candle manufacture—the softer materials melted first, and, overflowing the cup formed by the harder, caused the wasteful guttering referred to. Furthermore, glycerine, though valuable for many purposes, was of no use as an illuminant. By 1832 it was possible to separate stearine, the

most useful of the elements, from tallow on a commercial scale. Four years later patents were taken out for extracting the oil from cocoanuts; and in 1842 further discoveries had placed many kinds of greases, less expensive than tallow, at the disposal of the manufacturer. From that time onwards the whaling industry, which had grown and flourished on the demand for spermaceti, gradually declined as stearine grew in favour.

Another important date in the history of candle-making is 1850, for in that year *paraffin wax*, a white, transparent, solid substance, produced during the distillation of petroleum, made its first appearance as a candle material. The production of this useful wax was comparatively small till the opening up of the great oil-fields of America, but it has since increased to some 120,000 tons per annum.

Paraffin wax did not oust stearine, however, and for this reason: it is a substance which, under the influence of heat, becomes plastic before it reaches its melting-point; stearine does not. If you took a candle made of each substance and placed them, supported only at the ends, in a hot room, the stearine candle would remain straight, but the other would sag at the middle.

Fortunately this weakness can be overcome to a considerable extent by mixing paraffin wax with stearine; and the first, and not least important, part of the candlemaker's work consists in so blending the two substances that the desired rigidity in a warm atmosphere may be attained without sacrificing the transparency that is one of the chief attractions of paraffin wax.

To conclude these preliminary observations: (1) The two materials now most commonly employed in candle-making are stearine and paraffin; (2) stearine candles are best suited for a hot, stearo-paraffin for a moderately warm, and paraffin for a cold atmosphere; (3) candles made from beeswax or spermaceti are too expensive to be generally used.

We may now consider the preparation of stearine and paraffin.

STEARINE.

It has already been remarked that, generally speaking, the three most important elements of animal and vegetable fats are—(1) solid fatty acids (stearic and palmitic, commercially known as stearine); (2) liquid fatty acid (oleine); (3) a non-acid liquid (glycerine). Of these the first is the most useful to the candlemaker. The second

and third are valuable by-products. A large part of the "plant" (machinery) of the factory is devoted to separating stearine from oleine and glycerine.

The fats, whether animal or vegetable, undergo the following treatments:—

(*a*) They are melted from the casks in which they arrive, and clarified by *boiling*, to remove all fibrous matter.

(*b*) *Decomposition.* The purified fat is then transferred to a stout copper vessel called an "autoclave," or digester, and after some water and a little lime have been added, is subjected for several hours to a steam pressure of 120 lbs. to the square inch. The lime and water effect the separation of the fat into fatty acids and glycerine. When the decomposition is complete, the mixture is run from the autoclave into a tank, the glycerine is drawn off, and the lime is removed by means of weak sulphuric acid.

(*c*) *Acidification.* The fatty acids are next treated with strong sulphuric acid, which improves the colour, destroys undesirable substances, and converts some of the oleine into the more valuable stearine.

(*d*) *Distillation.* To purify the acids yet further, they are run into large stills, and heated by steam till they vaporize. The vapour and steam pass

through a series of upright condensers, from which the purified acids emerge as an almost colourless liquid, and flow into large tanks. From these they are run into shallow tins and allowed to cool gradually into solid cakes.

(*e*) *Pressing.* The cakes contain both stearine and oleine, and are fit for conversion into "composite" candles. But it is more desirable to separate the stearine, and use that only for candles. The cakes are therefore placed in flat canvas bags and squeezed twice in hydraulic presses, separated from one another on the first occasion by cold, and on the second by steam-heated plates. The oleine oozes through the canvas and is caught, but the more solid stearine cannot get through. The stearine emptied out of the bags is almost snow-white, and ready for the candle-making process. We may so leave it for a time, and consider the other important substance,—

PARAFFIN WAX.

This arrives at the factory in barrels or bags, and is of a more or less pronounced yellow colour. Before it can be used for candle-making it must have the colouring matter removed, and be rid of the softer paraffins and all oil.

The first stage in the refining is to remove the "scale," as it is called, from the barrels, and tip it into large underground tanks of several tons capacity, where it is melted by steam. It is pumped from these tanks into settling reservoirs, and, the water having been drawn off, is run into trays to cool. The trays are then placed in heated chambers and subjected to a carefully regulated temperature, just high enough to cause the softer paraffin to melt and flow away with any oil present, but not sufficient to affect the harder wax.

The latter after this process is much whiter than the crude paraffin scale, but needs further purification. This is effected by melting the wax in large agitators, and mixing with it some charcoal or other colour-removing carbon. The carbon is then allowed to settle, and the paraffin is blown by steam through pipes to the mixing-room in another part of the factory, where it meets the stearine.

A very important part of a candle is

THE WICK.

In the old-fashioned candle the wick consisted of fine threads of cotton lightly twisted together. During combustion the carbonized end remained

nearly erect in the flame, interfering with the combustion, unless removed frequently by the "snuffers" which formed part of the candlestick equipment. In 1825 a Frenchman named Cambacères discovered that if the threads were *braided* instead of being *twisted*, the wick would bend over, and its end be

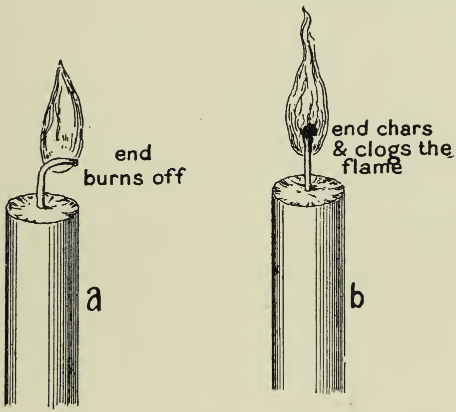


Fig. 29.—Showing how (*a*) a braided, (*b*) a twisted, wick burns.

burned off by projecting through the side of the flame. This was a very important discovery, and one that has practically saved the candle industry. Yet something more than braiding is required for the perfect wick. A means had to be found of removing the small quantity of ash or mineral matter present in the cotton, which if allowed to

remain would clog the wick. This is attained by soaking the wick in a chemical preparation, usually made by dissolving borax and sulphate of ammonia in pure water. Wick thus treated and then thoroughly dried burns correctly, the ash being converted into glass during combustion, and the minute glass particles dropping off from the bent wick, so as to leave the end free for the melted fat to ascend to the point where combustion takes place.

A wick is accurately proportioned to the amount of substance in the candle, in order that it may suck up the melted wax at a regular and constant rate. If it were too large, too much liquid material would be carried to the flame in a given time, and there would be imperfect combustion, resulting in a smoky flame. On the other hand, if it were too small, it would fail to consume all the melted matter, which would run down the side of the candle, and cause the guttering that renders tallow dips so objectionable.

It is an interesting sight to watch the wick-plaiting machines at work. Each has a number of spindles revolving about one another and interlacing a series of threads. As fast as it is made the wick is wound off on to reels.

FIG. 30.—In the Wick-plaiting Room.

We now come to the final stage, that of

CANDLE-MAKING.

Two methods are now commonly employed—(1) dipping, (2) moulding.

Dipping. Fig. 31 shows a dipping-machine. It consists of a long trough containing the melted fatty acids, and above it an iron frame suspended by chains passing over pulleys and counterbalanced by weights. The wicks are wound upon the frame, immersed in the melted fatty material, and allowed to remain there for a few seconds that they may be well saturated.

The frame is then raised and placed upon a rack to permit the material to solidify. After several dippings in this way the partially-formed candles are released from the iron frame by cutting, and transferred to wooden rods; and the alternate processes

FIG. 31.—Dipping Candles.

of dipping and cooling are continued until the dips have acquired a sufficient thickness, which is indicated by the weights of the machine.

Moulding is the process by which most candles are now made. It is said to have been introduced in the fifteenth century. Passing over the improvements

that have combined to bring the candle-moulding machine to its present state of perfection, we will give our special attention to the form now in general use.

Fig. 32 is a transverse section of a machine. AAAA are pewter moulds inserted in a water-tight tank, into which steam and cold water are alternately passed for the purpose of heating and cooling the moulds. They are arranged in two double rows, averaging twenty-four moulds to a row, or ninety-six moulds to a machine. Some machines have more, some less, the number decreasing with the increase in the size of the candles made by the machine.

A mould tapers slightly towards the bottom, which is closed by a piston shaped to produce the pointed tip of the candle. There is a hole in the bottom of the piston communicating with the piston rod P, which is a hollow tube, resting on a "lifting plate" L, raised or lowered by means of a rack R and pinions. In the bottom of the machine is a series of pegs carrying reels of wick.

The upper ends of the moulds open into a trough T, above which is a rack of "clamps" C.

We will suppose that a workman has just raised the lifting plate, and caused the pistons to push all the candles from the moulds up into the clamps.

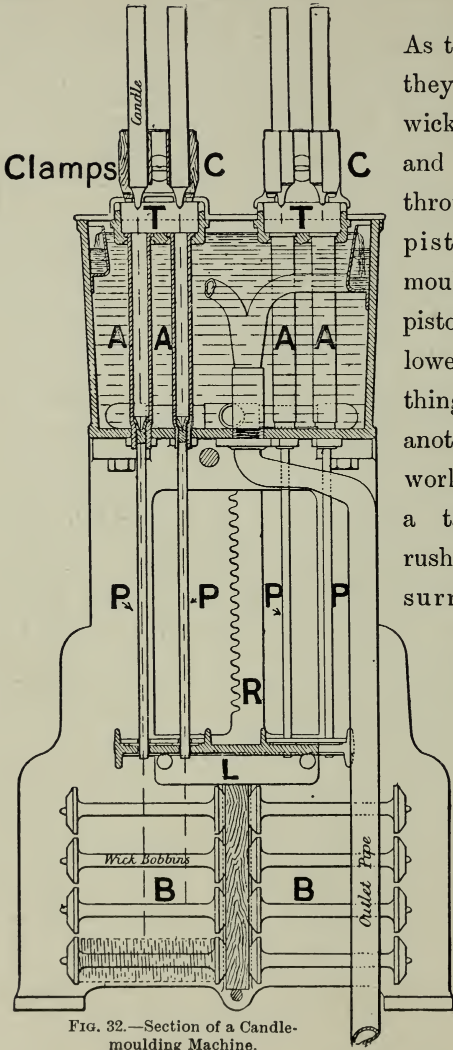


FIG. 32.—Section of a Candle-moulding Machine.

As the candles move they unwind the wick from the reels and draw it up through the hollow piston rods and moulds. When the pistons have been lowered again everything is ready for another "pour." The workman first turns a tap, and steam rushes into the tank surrounding the moulds, and heats them and the trough. When they are hot enough he dips out a pailful of the melted paraffin material from a large copper

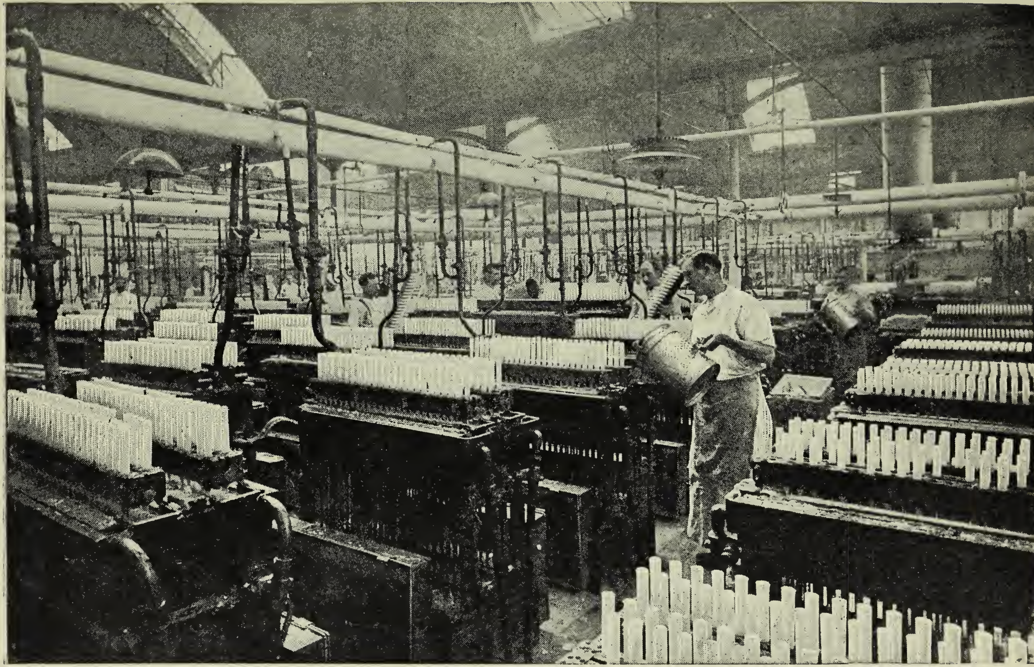


FIG. 33.—The Candle-moulding Room. The candles have been forced up into the clamps, and the attendant is filling up the troughs with a fresh supply of melted wax.

and empties it into the trough and the moulds below. After allowing time for the wax to settle down well, he turns off the steam and lets cold water flow through the tank until the candles are quite hard.

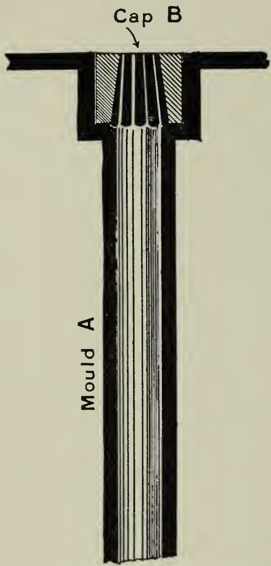


FIG. 34.—Mould for self-fitting Candle.

Then he takes a knife and cuts off the wicks of the candles in the clamps half an inch below the tips, discharges the clamps on to a table, clears the trough of material, and replaces the clamps above the moulds. The lifting plate is raised, and the last batch of candles is pushed up into the clamps. And so it goes on all through the day.

The process described applies to cylindrical candles. For candles with "self-fitting" or tapering ends some modifications are needed. The mould A (Fig. 34) is enlarged at its upper end to accommodate a cap B, which forms a fluted conical "butt," and when the candle is forced from the mould the cap is carried with it. Before filling the moulds with candle material the wick

needs to be threaded through the caps, which are then inserted in the tops of the moulds, the wicks being held over the centres of the moulds by a slotted iron bar passing over the top of each row of moulds.

For ornamental purposes spirally fluted candles are made. These revolve as they are pushed out of the moulds. The company makes candles of all sizes, from the tiny Christmas-tree candle, numbering about eighty to the pound, to the tall altar candle, five feet long, and scaling several pounds. Some of the larger candles are beautifully ornamented with transfer or hand-painted designs.

The most commonly used candles run four, six, eight, or twelve to the pound.

NIGHT LIGHTS.

These short, thick candles are very valuable for lighting nurseries and sickrooms. Their delicate construction demands more careful methods of manufacture than those required for the ordinary candle.

Messrs. Price make two kinds of night lights—(1) in paper cases, intended to be burnt in a saucer containing a little water (to obviate risks of fire); (2) without cases, to be burnt in small glass jars.

The manufacture of the first being, perhaps, the more interesting, we will confine ourselves to a notice of it. The machines for moulding are somewhat similar to those employed for ordinary candles, but the wick is inserted separately by hand.

The cases are made as follows:—Long strips of thin cardboard printed on one side are rolled round wooden cylinders and glued. After being dried and polished, they are handed over to girls, who slip them on to a wooden lathe mandrel, and as they revolve divide them into several rings, each of which is the cover of a night light.

Other operatives stick in the bottoms—circular discs of cardboard—and to them affix the short wicks, which are passed through a piece of perforated tin to act as a support. The wax portion of the light, which has had a central hole formed in it by the moulding-machine, is slipped over the wick, and the light is then finished.

From each batch several lights are taken and burned in a glazed cupboard, that their quality may be ascertained. I noticed with some interest that three lights which had started together had simultaneously reached their "last gasp," thereby proving the careful proportioning of the wicks.

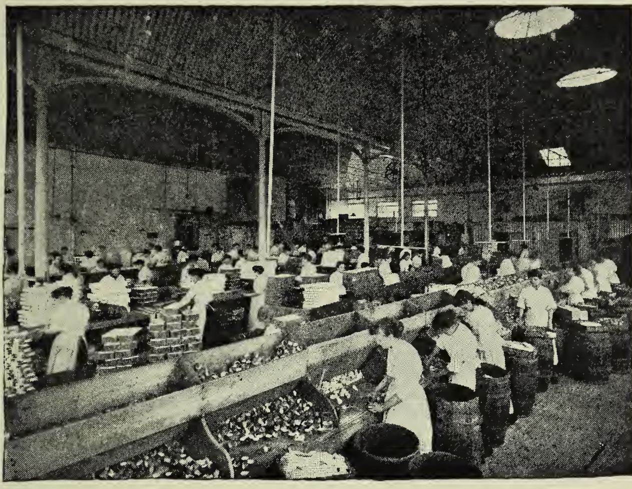


FIG. 35.—Affixing the bottoms to Night-light Cases.

SOAP.

Soap is a compound of fatty acids, the alkalies soda and potash, and water. The alkali may be said to be the essential cleansing element, but it cannot be conveniently used alone, or "free," lest it should injure the skin. So it is combined with fatty acids to form a solid substance which, when rubbed in water, gradually releases the alkali. The fatty acid is practically nothing more than a "vehicle," playing the same part in soap that sugar, starch, etc., play in medicinal lozenges.

For the manufacture of "hard" soaps, tallow and other animal fats, cocoanut and other vegetable oils, and resin are boiled with a solution of caustic soda in huge coppers of many tons capacity. The addition of some common salt causes the uncombined soda, water, and glycerine liberated from the fats to separate from the soap, which is boiled again, and finally run, while still warm, into large wooden or iron frames, where it is left until cold. The sides of the frame are then removed, and the blocks of soap are cut into slabs, and then again into bars, by special machines.

"Soft" soaps are made from vegetable oils and a solution of potash, but are not salted, all the elements being allowed to remain.

"Toilet" soaps are generally prepared from hard or yellow soap. Great care is taken that there shall be no "free" or uncombined alkali present, for the reason given above. The process of making the best soaps may be thus described.

The molten soap, fresh from the copper, is stored in a large tank over the mixing apparatus. It is then passed between several powerful iron rollers, which partly cool and thoroughly knead it. A row of iron teeth pressing upon the bottom roller detaches

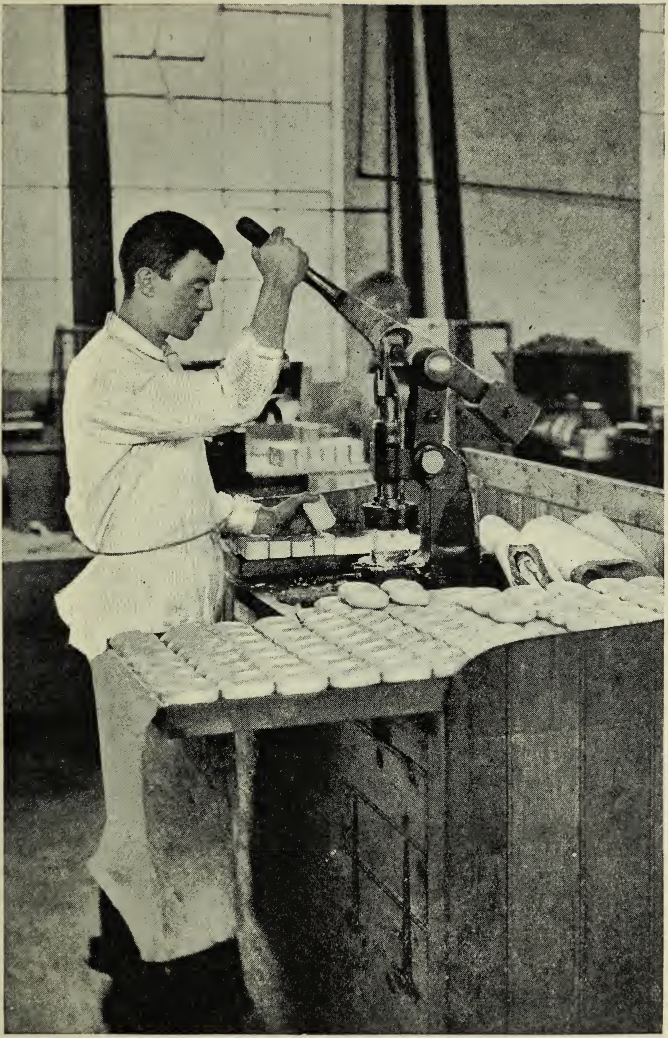


Fig. 36.—Stamping Blocks of Soap.

the soap in the form of thin ribbons, which fall upon a band of very thin wire gauze, and are carried by it through a heated, well-ventilated chamber, where they are deprived of most of their moisture. The colouring matter and perfume are then added, and the mass is well kneaded in another machine, which squeezes the strips together and presses the soap out through a nozzle as a continuous bar, which is divided by a knife into blocks of a certain length. Each block is placed in a press, the dies of which shape it and stamp it with its own and the makers' name. After a few days' exposure to the atmosphere, the tablets are wrapped, and are packed in cardboard boxes bearing artistically-designed labels, or in wooden cases.

I must not conclude without acknowledging my indebtedness to Mr. John M'Arthur, the general technical manager of the Company, who spent several hours in showing me the various processes which convert paraffin wax, fats, and other substances into the articles mentioned at the head of this chapter.

[*Note.*—The photographs illustrating this chapter were kindly supplied by Messrs. Price's Patent Candle Co., Ltd.]

Chapter VI.

A MINERAL-WATER FACTORY.

What mineral waters are composed of—Making the gas—Bottling —The pressure of gas in a bottle—Filling syphons.

I HAD often wondered how bottles and syphons of soda water and lemonade were filled; and having heard that the machinery used was ingenious, I made a journey to a big mineral-water factory at Camberwell to see the whole process of mineral-water manufacture.

The sight of thousands upon thousands of the familiar wooden cases used for holding dozens of bottles, stacked tier above tier in the yard outside the factory, suggested that the output must be very large, and I learnt that two thousand gross represents one day's work when the weather is warm and the demand for such drinks is brisk. This factory is but one of a large number owned by the same firm.

Soda water is pure water charged with carbonic acid gas. Lemonade has a sweet syrup added to the

water. And we may say that other drinks of the same class all contain carbonic acid gas as their "fizzy" element.

At one corner of the premises is the gas-making plant. The generators are four large cylindrical chambers of oak, in which is placed a quantity of whitening (powdered chalk) and sulphuric acid. Agitators, driven by steam, revolve inside the chambers and mix the two materials together. The oxygen of the acid unites with the carbon of the chalk and forms carbon dioxide (known chemically as CO_2, consisting of two atoms of oxygen to one of carbon in the molecule), which, after passing through a purifier, ascends to a gasometer to be stored for use.

Underground pipes lead the gas into the bottling-room. At one end is a row of pumps, each of which has two supply pipes, one from the gas main, the other from the water main. By means of taps the proportion of gas and water is regulated. The mixture is forced into a cylindrical chamber, whence the pressure drives it to the bottling-machines. There are dozens of these, each presided over by a bustling employee, who seizes an empty bottle with the stopper in position, and places it in the machine.

The stopper is automatically unscrewed, and a charge of gas-laden water is forced in, syrup is added (in the case of lemonade or other flavoured beverages), and the stopper is replaced. The operation is completed in a very short time—an expert girl will pass forty gross of bottles through the machine in a day.

The gas pressure in a soda-water bottle is 100 lbs. to 120 lbs. to the square inch, and in a lemonade bottle about 80 lbs. So the bottles have to be thick and heavy. Every now and then a loud report is heard, as a stopper flies out or a bottle bursts; and you understand why the women wear masks and the door of the bottling-machine is closed while a bottle is being charged.

A different type of machine is used for filling syphons. The syphon is placed on its head in a socket, and when the employee pushes a lever down an arm rises and opens the valve of the syphon by depressing the little valve lever. Then in rushes the charge through the nozzle, and the moment the syphon is full the valve is closed.

Chapter VII.

CHINAWARE AND POTTERY.

Body and glaze—China—Its introduction into Europe and England—The Worcester Royal Porcelain Works—Materials used in china-making—The mill—The slip-house—Magnets—Shaping the clay—A potter's wheel—Moulding—Turning—Affixing a handle—Plates and dishes—Ornamental pottery—Casting—Baking—Seggars—The "biscuit" oven—Dipping—The "glost" oven—Decorating—Printed designs—Artists at work—An ingenious oven—The Staffordshire Potteries.

CUPS, saucers, plates, dishes, bowls, which we use on the table and in the kitchen, and also "china" articles of all descriptions, consist of (1) the *body*, or main bulk, which is shaped by the potter; and (2) the *glaze*, or transparent, hard, waterproof coating given to the body after it has been baked.

Since all classes of pottery have many—one might almost say all—processes in common, I have thought it advisable to take my readers to the Worcester Royal Porcelain Works, where some of the most beautiful ware manufactured in the world has its origin. Before we enter the doors let me explain that porcelain, or china, differs from ordinary pottery in

being semi-transparent. In the country from which it derives its best-known name the secrets of china-making have been known and practised for many centuries. During the Middle Ages a piece of "china" was a gift worthy of the acceptance of a king; and though Europeans tried hard to discover the art of making this delicate and translucent ware, it was not until about the end of the sixteenth century that the

Fig. 37.—Specimens of Worcester China.

Italian potters found in kaolin, a certain kind of clay, the substance which gives china its peculiar qualities. The Italians, in turn, kept the discovery to themselves; so did the Germans and the French when they too made it; and we do not find the manufacture of porcelain included among English industries till about the year 1680, when one John Dwight took out a patent for special methods of porcelain work. The Worcester factory was established in 1751 by Dr.

Wall, a physician, who, though he could not command a good supply of coal or clay or skilled labour, succeeded in producing a most beautiful soft porcelain, fit to rank beside those of Dresden and Sèvres.

The visitor is first shown the raw materials used on the premises—Cornish granite and china clay, oxbone for increasing transparency, flint, fireclay, Swedish felspar, and silica, which looks like lumps of glass. He then proceeds to the

MILL,

where, on the upper floors, are large pans about ten feet in diameter, somewhat like those of a mortar mixer, in which heavy masses of stone are dragged round and round by machinery. The materials to be ground are thrown into the pans, water is added to the depth of several inches, and the mill is set in motion and kept running for a period of from twelve hours to ten days, according to the substance under treatment, until the heavy stones have crushed the substance thoroughly, and caused it and the water to form a liquid of the consistency of thick cream. The liquid is then strained through sieves of silk lawn having about 4,000 meshes to the square inch, and run into the big tanks in the

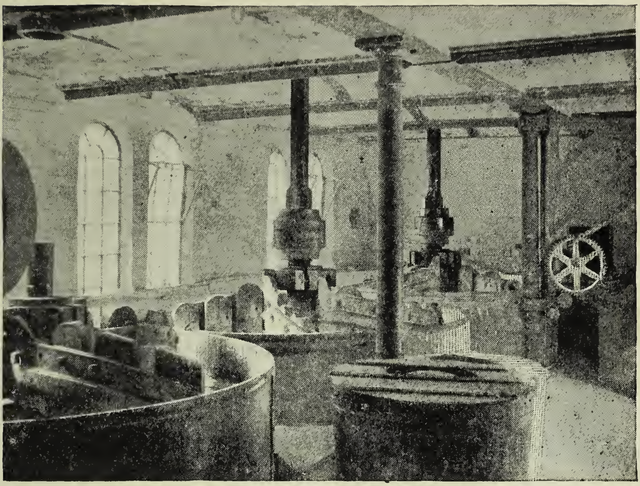


FIG. 38.—The Mill.

SLIP-HOUSE.

China clay, being naturally crumbling, does not need grinding, and has merely to be well mixed by machinery with water. In the slip-house the clay, bone, fireclay, etc., creams are stirred up together in a big mixing-pot. You may perhaps be surprised to see that the arms revolving in the pot carry a number of horse-shoe magnets. If you ask what their purpose is, you will be told that they remove from the mixture any particles of iron that may have got into it. The "slip," as the finished mixture is called, is

run out through troughs—also containing magnets well feathered with minute iron fragments which they have attracted—into a series of very fine sieves shaken mechanically. After passing them it runs into a tank,

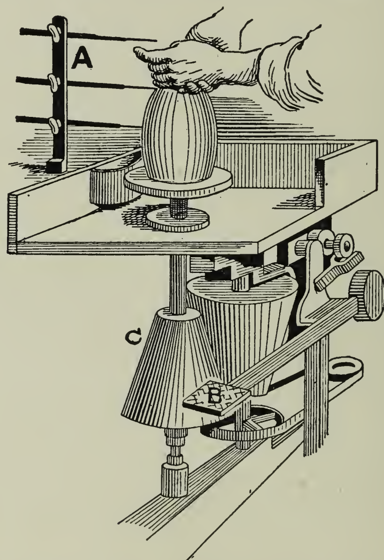


FIG. 39.—A Potter's Wheel.—A, Gauges for shape of article; B, lever for stopping; C, gear cones.

and thence is pumped into the chambers of a hydraulic press, which squeezes out the water and transforms the "slip" into clay of the consistency of dough. A good thumping and pummelling follows, and the clay is ready for the workman.

SHAPING THE CLAY.

For deep circular vessels like cups and vases the potter's wheel—the same in principle to-day as it was five thousand years ago—is used: a flat, circular table revolving on a vertical shaft. In this factory

Fig. 40.—A "Thrower" at work.

motive power is supplied by steam instead of the potter's foot, acting on a heavy flywheel attached to the bottom of the shaft; and any one who takes an interest in mechanical matters may notice that a

gear is provided for suiting the speed of revolution to the nature of the article that the potter has to mould.

A person who works at a potter's wheel is known as a "thrower." He takes from an assistant a ball of clay, *throws* it upon the centre of the wheel, and presses it with both hands. As if by magic, the clay

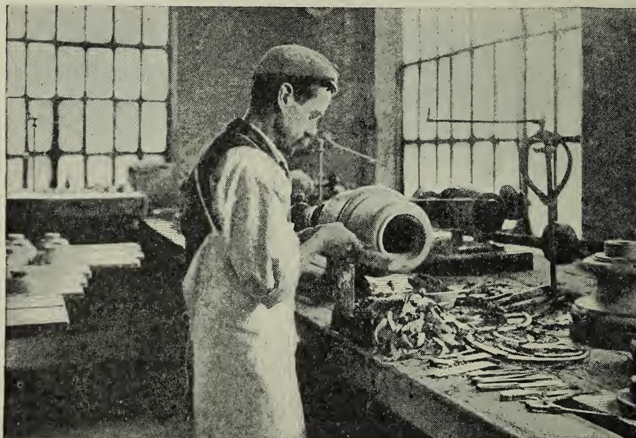


FIG. 41.—A "Turner" at work.

rises in the shape of a cone. He beats it down, and allows it to rise a second time; and then pressing a thumb on to the mass, and holding his other hand up against the lump, quickly forms what looks like a rather round-bottomed flower-pot. This is the "lining" or first stage of a teacup—the outside any-

thing but smooth, and the inside as yet only half formed. So the thrower places the lining in a plaster-of-Paris mould, and with a piece of slate cut to the curve of a cup's interior forces the side against the mould, and removes superfluous clay. The plaster absorbs some of the moisture, and in a few minutes the now stiff cup is taken out and handed over to the "turner" (Fig. 41), who fixes the ware upon his lathe,

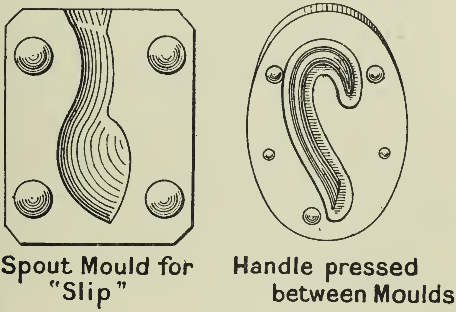


Fig. 42.

touches up the outside surface, and with a nicked "shaper" raises the circular, protruding ring, called the foot, on the bottom.

Next comes the fitting of the handle. Handles are made by pressing a piece of clay, bent roughly to shape, between two moulds (Fig. 42). The "handler" trims up a handle, hollows out the ends slightly where they will touch the cup, and affixes it with

a little liquid "slip," which is sufficiently sticky to enable you to lift up the cup by the handle immediately after the two parts have been joined.

FIG. 43.—Fixing Spout on a Teapot.

Perhaps you are tempted to remark that for teacups the cups look very large, and you learn that a cup shrinks every way when baked, and afterwards has only about half its original capacity.

PLATES AND DISHES

are made in a somewhat similar manner. For plates the clay is beaten out into thin discs (Fig. 44), and laid on a mould having the shape of the face of the plate, and pressed down into place, while the

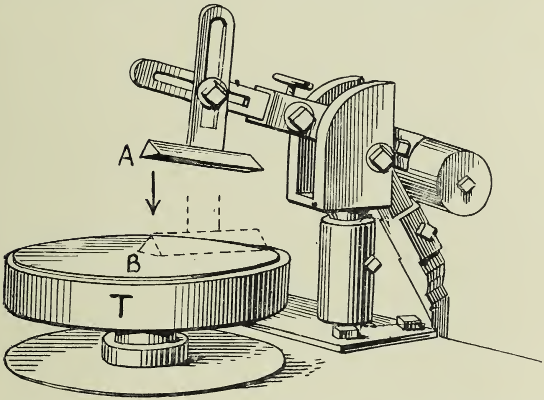


Fig. 44.—Flattening out clay for a Saucer.—T is the revolving table; A, the flattening tool; B, the disc of clay.

mould is revolved on a table like that of the potter's wheel. The back is finished off and the foot raised by a "profile" tool cut to half an outline of the plate (Fig. 45). Then mould and plate are set in a stove to dry, and as soon as the plate shrinks it is removed and touched up in a lathe. Objects which are not circular—dishes, soup tureens, etc.—have to be

shaped by pressing clay into moulds without the assistance of a lathe. If the vessel contracts towards the top, the mould has to be divisible, otherwise the vessel could not be got out of it.

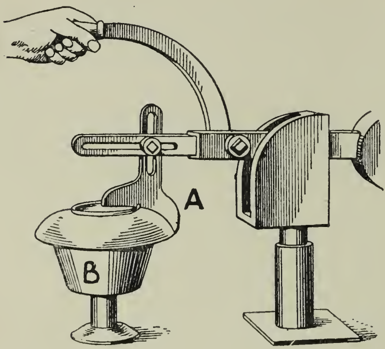


FIG. 45.—Shaping a Saucer.—A, Profile tool; B, table.

ORNAMENTAL POTTERY

We now come to the most interesting process of pottery—that of making objects with irregular outlines, such as ornamental vases and statuary. Let us suppose that an order has been received for a china candlestick supported by a human figure. The idea is first designed and worked out by sculptors, who make the model sufficiently over-sized to allow for shrinkage in the baking. The model is then cut up into parts, each of such a shape as to be easily released from a mould; and from these parts divisible plaster moulds are made. In the showroom are a pair of most beautiful vases, which required, so I was told, no less than one

hundred and fifty different sets of moulds for their many parts.

The china used in this kind of work is kept in the "slip" or liquid form. The moulder closes a mould,

Fig. 46.—Trimming up parts of raw clay.

and fills it with slip through an orifice left for the purpose, and allows the slip to stand for a while (Fig. 47). The plaster quickly sucks the moisture out of the slip that touches it, so that in a few minutes

the "cast" has a semi-solid exterior. The liquid centre is poured back into the casting jug, and the lining is given time to become stiff before the pieces of the mould are stripped off it.

As soon as all the various portions of the design have been cast in this manner, the workman trims off the superfluous clay from each, and sticks them to-

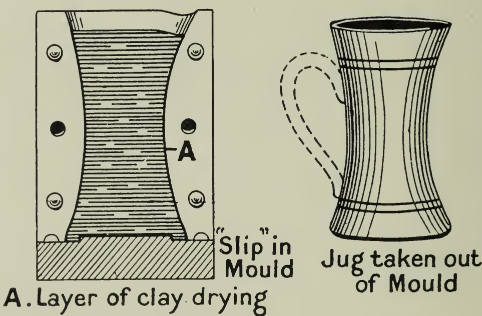


Fig. 47.

gether with slip, each in its proper place, until the whole is built up. The joints having now been wiped clean with a camel's-hair brush, and clay props fixed wherever necessary, the object is ready for the oven.

In one room that I entered a very skilful and artistic workman was ornamenting vases and plates with numbers of holes set so close together as to resemble lacework in clay. Every hole had to be

cut in exactly the right place and of a certain size. One false stroke, and the work of days would be wasted. After showing me with pride some of his really magnificent productions, the man explained how it came about that certain kinds of ornamental work were so very expensive. He took the case of a certain big vase, the mould for which weighed half a ton. During the first cast the mould burst, and forty gallons of slip were wasted. The mould was repaired, and a successful cast made. The design was cut and finished, but the vase cracked in the oven. A third attempt was successful, and a beautiful vase resulted.

BAKING.

Pottery of all kinds has to undergo at least two bakings—one to harden the clay, the other to "fire" the glaze.

The oven or kiln used for the first baking is called the "biscuit" oven. A china oven is about 14 feet in diameter, and has a domed roof with a hole in the centre, through which the smoke of the eight furnaces beneath escapes (Fig. 48).

The objects to be baked are placed in strong fireclay pans, named "seggars" (Fig. 49), shaped to suit the different wares. For flat objects the work-

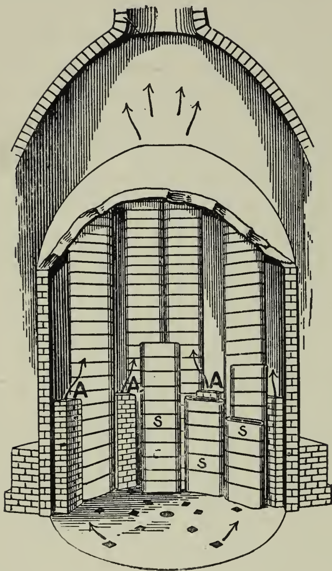


FIG. 48.—A "Biscuit" Oven filled with "Seggars" S. AA are the flues.

men prepare in the seggars beds of powdered flint, a substance which does not melt or stick to the china. Cups, bowls, and other hollow pieces are grouped together in oval seggars; and in the mouth of each is placed a conical ring of unbaked china, to prevent distortion during the baking. As fast as the seggars are filled they are stacked one on the other, and the spaces between them stopped with clay so that no smoke may reach the contents.

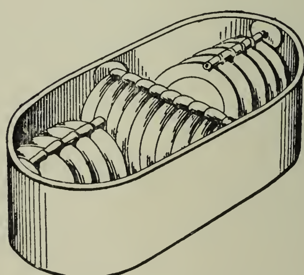


FIG. 49.—A "Seggar" filled with Plates.

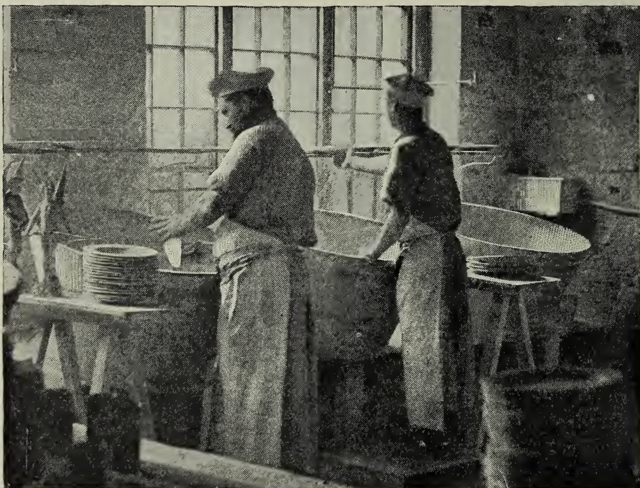
The oven being filled—and it takes some days to do it—the door is bricked up, and the fires are started, and kept going for about forty hours. Fifteen

tons or more of fuel are required for a firing, in order to maintain the temperature inside at about 3,000° F. At this heat the seggars and the things inside them become so transparent that if you peep in at one of the spy-holes through which the workmen extract small test cups from time to time, to see how a baking progresses, you can perceive nothing but a dazzling glare. But when the fires are stopped, and the seggars have cooled to red heat, their outlines become visible.

The need for bedding and supporting articles for the oven is due to the fact that at one stage of the firing the clay has the consistency of a blanc-mange, and in spite of all precautions it sometimes happens that a costly vase collapses with the heat.

When the oven has cooled for two or three days, the entrance is unbricked and the seggars are taken out. The porcelain has now reached the "biscuit" stage, and its surface is dull and rough enough for you to mark it with a lead pencil. To produce a smooth, shining surface the porcelain must be dipped in a glaze of a glassy nature by a workman who through long practice is able to distribute the liquid equally, be dried in a stove, and be placed in seggars and baked in a "glost" oven for sixteen hours. The temperature in this oven is not so high as in the

biscuit oven. One of the great difficulties in pottery-making is to find a glaze to suit the "body" of the article it has to cover. It must melt at a lower temperature than that required to bake the body; and yet the difference between the temperatures must not



F.G. 50.—Dipping "Biscuit" China in glaze.

be too great, or the glaze may not unite properly with the body, and crack on cooling.

DECORATING

is done by hand or mechanically, or by the combination of both processes.

Printed designs are most commonly used for flat ware. They are engraved by artists on copper plates, over which the colour, mixed with oil, is spread. The workman wipes off all the colour except that which stays in the engraved lines, and applies a sheet of moist tissue paper to the copper plate. They are run together through a press, which causes the colour to leave the copper and cling to the paper, so that when the latter is loosened it carries all the colouring matter of the design.

The paper is then applied to the article, and soaked off in water, leaving the design on its new support. The latter part of the process will be followed easily by any one who has used the coloured transfers sold in sheets for the decoration of note-paper or albums.

Over-glaze designs of this kind are put on an article *after* it has passed through the glost oven, under-glaze designs on the biscuit *before* dipping.

Hand decoration is the more interesting process from the visitor's point of view, because in this case great skill is required for the treatment of every separate article, the colouring is more complicated, and the design more original.

Several large rooms and the services of a large

staff of artists are devoted to the beautifying of china with landscapes, birds, flowers, and other subjects, framed in a border of gold. The subject is first sketched in India ink. Then the first "wash" of colours (prepared from metallic oxides) is given. We

FIG. 51.—Painting on Porcelain.

must observe that the various colours undergo a change during the baking, and so the artist has to be very careful. Thus the gold in its raw state is black, black is blue, pink is a dark brown—in short, his palette would sadly deceive the uninitiated. Then,

again, the different colours require different temperatures to set them; and as it is no uncommon occurrence for a vase to be baked eight or nine times in the special kilns used for "over-glaze" colours before the design is complete, the artist must consider the order of applying the pigments. The colour-setting kilns are circular tunnels, heated at the side opposite to the entrance. The boxes containing the articles to be fired are moved on periodically inside the tunnel, heating gradually as they approach the furnace, and cooling again during their retreat to the entrance. The process occupies about thirty hours.

Gold surfaces are either scoured with fine sand, if a dull finish is required, or rubbed with agate points till they shine brightly. The quicksilver which was mixed with the gold to make a liquid paint evaporates in the ovens, leaving only pure gold to be treated in one of the ways described.

The manufacture of sternly "useful" earthenware and pottery has its centre in the Potteries of Staffordshire, where about seventy thousand people are engaged in the industry. Improvements in mechanical appliances and the increase of technical knowledge have greatly advanced the quality and appearance of even the commonest ware, and rendered possible the pro-

duction of very large articles, such as baths and glazed pipes a yard in diameter. It may be said that pottery is gaining a larger scope year by year, owing to the increasing demand for articles with an unchangeable and easily cleaned exterior.

Chapter VIII.

THE MANUFACTURE OF GLASS.

A story: how glass was discovered—Constituents of glass—Glass-making—A tank furnace—Shaping glass—Blowing bottles—Window-glass—Large sheets—Rolling plate-glass—Pressing glass—A stopper-making machine.

ACCORDING to a well-known story, glass was discovered by some Phœnician sailors as the result of lighting a big wood fire on the seashore. The wood-ash united with the sand under the influence of the heat, and much to the sailors' surprise, when they scattered the fire they found below it a clear, translucent substance, of which they at once recognized the value.

From a purely chemical point of view the story is plausible enough, as sand supplies silicon, the foundation material of glass, and the wood-ash contains an alkaline "base" necessary to give transparency; but the manufacturer, who knows that intense heat * is needed to fuse the materials that go to the

* For some glasses 13,000° F.

making of glass, will probably be unable to give the narrative much credit.

There are three kinds of glass in common use, all containing—(1) sand (silica), as the acid element; (2) soda or potash, as the alkaline "base;" (3) lime or oxide of lead, as the alkaline earth.

FLINT-GLASS

—made of sand, 100 parts; red lead, 70 parts; potassium carbonate, 33 parts—is employed mainly for the manufacture of tumblers and other table-ware, and for ornamental objects. It has a naturally brilliant surface, which is improved by cutting and polishing on grindstones and emery wheels. The presence of the lead renders it fusible at a comparatively low temperature, and so particularly suitable for the manufacture of *pressed* goods.

CROWN-GLASS

—sand, 100 parts; carbonate of soda, 33 parts; lime, 15 parts; cullet, or glass scrap, 100 parts—is used for *plate* and *window* glass.

BOTTLE-GLASS.

For common bottle-glass the materials generally

used are sand, gas-lime, and salt; but other materials are also employed in different districts.

MAKING THE GLASS.

Flint-glass is fused out of contact with the furnace flames, as the sulphur in the gases of combustion has an affinity for lead and would cause discoloration. Fig. 57 (6) shows a pot used for melting flint-glass. The orifice at the top is arranged

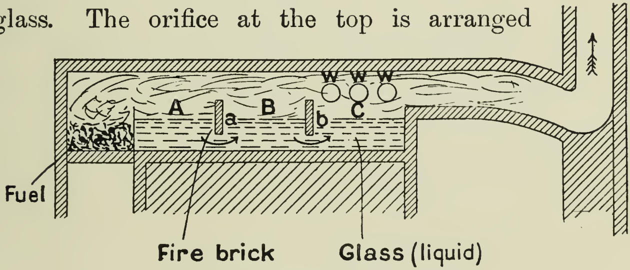


FIG. 52.—Section of Glass Tank Furnace.

opposite a hole in the furnace wall, through which the workman extracts the "metal," as liquid glass is called.

For window and bottle glass the *tank furnace*, holding many tons, has now established itself. The tank is divided transversely into three divisions by partitions which do not quite touch the bottom, and is domed over (Fig. 52). At one end is a coal or gas fire, the flames of which sweep from end to end of the

tank on their way to the chimney. The raw materials, called the "batch," are shovelled into compartment A, where they melt. They then pass under bridge *a* to compartment B, where the "metal" is purified; and under bridge *b* to compartment C, the walls of which are perforated with "working holes" W. In some bottle factories the tank is not divided in this manner, and there are working holes all along the sides of the tank. In order to prevent the scum from interfering with the quality of the bottles, a fireclay pot, perforated at the lower end, runs from each hole to the bottom of the tank (Fig. 53), where the metal is pure.

For the manufacture of plate-glass the "batch" is melted in huge fireclay pots, which are removed bodily from the furnace to be poured.

SHAPING GLASS.

Glass is shaped in three ways—(1) blown; (2) rolled; (3) pressed.

GLASS-BLOWING

is used for fashioning bottles, lamp-glasses, bowls, and other objects, and in the making of window-glass.

Bottle-making consists of expanding a bulb of

soft glass against the interior of a cast-iron mould, in the walls of which is sunk any pattern or moulding that the outside of the bottle is to bear in relief. The mould is in two halves, hinged together at the bottom. One half is fixed to the

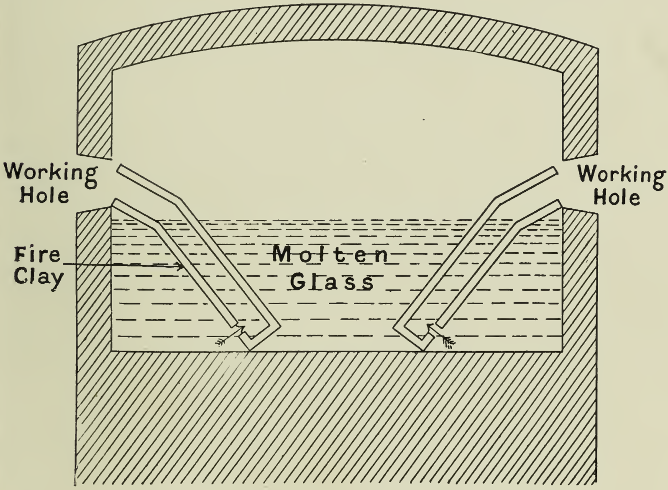


FIG. 53.—Transverse section of Glass Tank Furnace.

floor; the other can be opened by a rod attached to the upper end.

The workman begins by collecting a blob of red-hot glass on the end of his iron blowpipe, rolling it on an iron "marvering" slab greased with bees-wax, and waving it in the air, blowing gently the

while. As soon as the bulb has attained a certain size, he opens the mould with his left hand and encloses the bulb. Blowing is then continued until the glass touches the mould at all points, when the mould is opened and the bottle removed and broken off at the neck. In "burst-off" work the rough end is merely ground down on a stone after annealing. In "made" work a smooth finished and moulded end is formed in the following manner. An assistant, termed a "finisher," picks up the bottle in a "gauge"—an iron bar with sheet-iron jaws at one end which fit the bottle—and presents the neck to the furnace flames. When the end is red-hot and soft, he takes his seat in a kind of arm-chair and rolls the gauge backwards and forwards along the arms, shaping the neck with a "bowls," which may best be described as a large pair of sugar-tongs with a central shaft of the same length between the two ends. The shaft terminates in a piece of brass, which is inserted in the neck to form the inside of the mouth; and the tongs carry brasses to shape the outside when the tongs are squeezed against the glass by the finisher.

The shaped bottle is lifted on a fork, and transferred to a "leer," or annealing oven. All glass

articles are extremely brittle after the shaping stage, which has cooled the glass very quickly. It is therefore necessary to reheat them to a dull red, and allow them to cool gradually, before they are

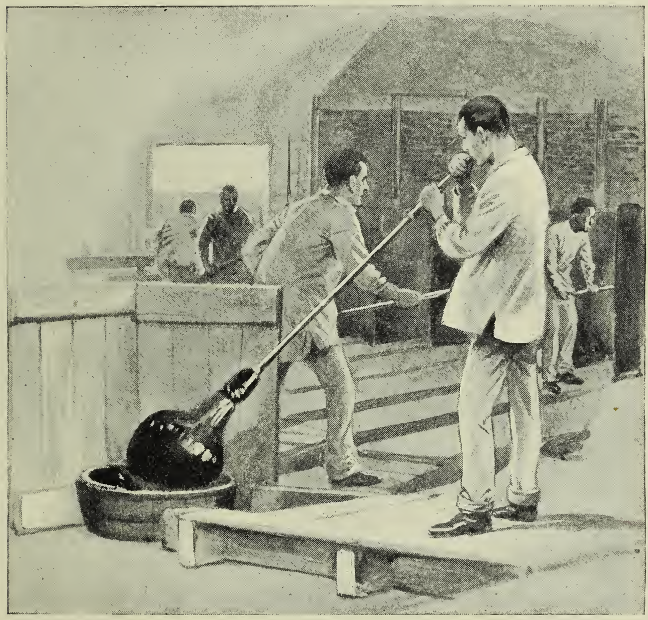


Fig. 54.—Blowing the Ball for a Glass Cylinder.

fit for use. A bottle leer is simply a long firebrick tunnel heated from the end at which the bottles are introduced in large iron trays. When a tray is put in, it pushes its predecessors a little way

towards the exit, and so in the course of a few hours a bottle passes through the tunnel.

Window or *sheet glass* making is entirely blowing work. The workman collects about 25 lbs. of glass on the end of his tube, and works the mass into a cylindrical shape on a hollow "marvering" block. He then blows and spins it simultaneously till it expands into a flattened ball (Fig. 55), 12 inches to 18 inches in diameter. The next step is to draw out the bottom half of the ball into a long cylinder of the same diameter. This is done by heating the glass at a circular hole in a special furnace, and swinging it through part of a circle over and in a long, deep pit, at the edge of which the workman stands. After several reheatings a closed cylinder from 4 feet to 7 feet long, according to the skill of the workman, is obtained. The cylinder is then burst open by blowing it full of air and heating the end, which gives way in the centre under the pressure of the expanding air inside. Further heating and rapid twisting of the blowpipe "flushes out" the end in line with the rest of the

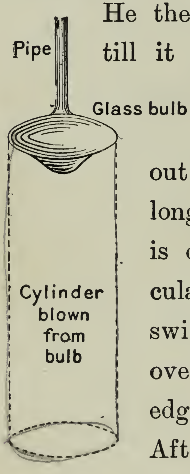


Fig. 55.

cylinder. The cylinder has then to be separated from the blowpipe end, by passing a thread of hot glass round the circumference and withdrawing it suddenly, and applying a cold iron to the line touched by the thread. The sudden cooling cracks

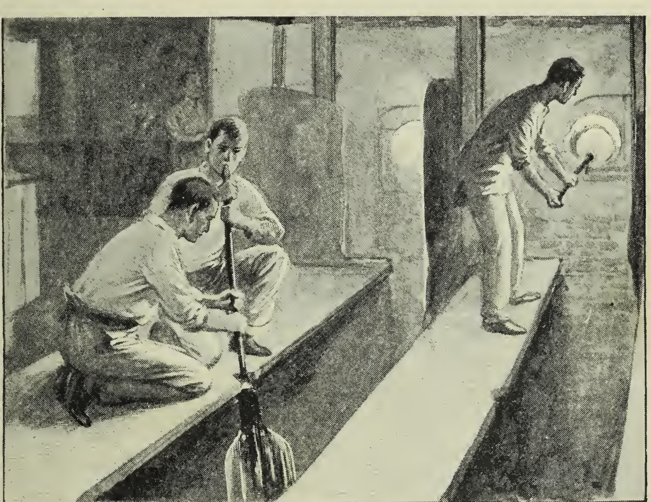


Fig. 56.—Blowing a Glass Cylinder.

the cylinder off. A rim is cut off the rough end with a diamond, and the cylinder is split longitudinally by a cutter drawn along the inside, and laid in a heating oven, split uppermost, until the glass softens and flattens out by its own weight into a sheet. From the oven the sheet goes to the anneal-

ing furnace, where it is placed on end and gradually cooled.

The largest sheets made measure about 7 feet by 4 feet, but only few workmen are sufficiently skilful to blow the cylinders required for such sizes. Sheet-glass is classed by the number of ounces that a square foot of it weighs—" 12-oz.," " 18-oz.," " 20-oz." glass.

Blowing and *drawing* and *shaping by hand* are used in combination for such things as wine glasses and vases (Fig. 57), which begin as a bulb, have stems drawn from the tip by the application of an iron rod, and, after being detached from the blowpipe, are reheated and shaped by the pressure of a tool on the free edge. Glass *tubes* are made by drawing out a bulb of glass from both ends, the size depending on the speed at which the drawing is done; glass *rods* by similarly extending a solid mass of glass.

GLASS-ROLLING

is necessary for the manufacture of very thick sheet-glass, generally known as *plate*-glass. The apparatus used is a large flat iron table over which a roller is run, resting at each end on two strips of iron of the thickness of the plate required. The width of the

FIG. 57.—The Processes of Glass Manufacture.—1–5. Making flint-glass for windows. 6. Melting-pot for flint-glass. 7. Making glass tubing.

(Sketched at Messrs. Powell's Glass Works, Blackfriars.)

plate is determined by two parallel moving guides with ends cut to fit the roller. To roll a plate, a large pot of metal is drawn from the furnace and poured out on the table in front of the roller and between the guides. The roller advances, pushing

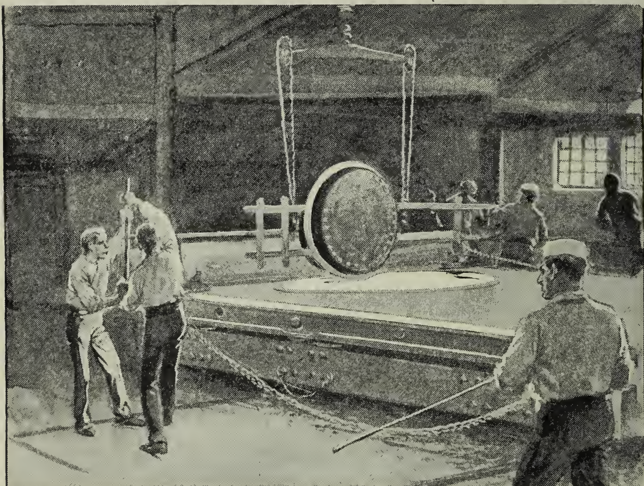


FIG. 58.—Pouring molten glass on to table for rolling.

before it the guides and all the glass except what is required to make a layer as deep as the distance between the roller and the table, the guides preventing the glass from spreading laterally.

The plate so obtained has uneven, wavy faces, and consequently is not transparent. After being

annealed in special leers, the plate is therefore laid on a big revolving table, and has the faces ground quite smooth and parallel to each other by flat rubbers pivoted on a beam spanning the table, and rotated automatically by friction against the glass. For the first grinding coarse sand is used; afterwards emery powder of graduated fineness; and lastly, rouge. The process is slow, as more than a third of the substance of the rough plate has to be removed, and plate-glass is therefore expensive. Despite difficulties of handling, plates 15 feet by 25 feet have been successfully rolled, annealed, ground, and polished.

PRESSING GLASS.

Tumblers, vases, and bowls, both plain and ornamental, are now very commonly made by compressing glass mechanically into moulds. A pressing-mould is constructed of several very accurately fitting parts which can be easily closed together or taken apart. To make a tumbler, a sufficient quantity of semi-solid glass is placed in the mould and squeezed by a plunger having the shape of the interior of the tumbler, till it rises and fills the space between the plunger and the mould. In this manner it is possible to manufacture elaborately patterned ware, the design

being engraved very carefully in the walls of the mould. Machines are now used for making bottles and lamp glasses partly by squeezing, partly by blowing with compressed air. We may here mention a simple apparatus for making glass stoppers with flat heads and tapering shanks, such as are used

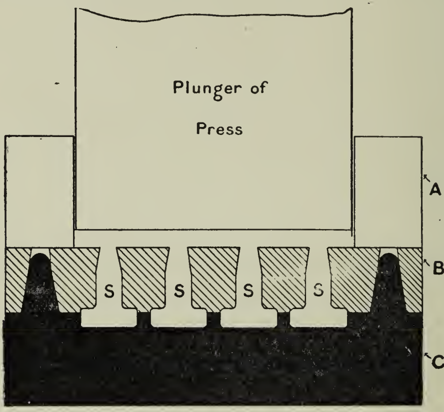


Fig. 59.—Glass Stopper Mould.

for sauce bottles. A section of it is given in Fig. 59. The solid black part C, the "bed," has a number of circular depressions sunk in its upper face, immediately below an equal number of holes in the "centre" B, and also two projecting pegs for maintaining B in its correct position. When a "nest" of stoppers is about to be pressed, the workman places B on C, and lowers

a "collar" A on to the top of B. The collar having been partly filled with soft glass, the plunger is lowered to force the glass into the spaces S S. Plunger and collar are then withdrawn, the superfluous glass above B is cut away with a knife, B is raised off A, and the stoppers are shaken or pressed out of it.

Chapter IX.

THE MAKING OF A PHOTOGRAPHIC PLATE.

Not an easy matter—Cleaning the glass by machinery—Applying the "substratum"—Drying—The coating machine—Cooling the emulsion—Cutting the plates—Films.

ALMOST everybody nowadays is, or has been, or wishes to be a photographer, and therefore feels interested in the glass plates and films coated with a preparation of silver salts extremely sensitive to the action of light. It may seem a very simple thing to pour some liquid "emulsion," as the preparation is called, over a piece of glass or celluloid, and let it dry. And so it is. But to manage it in such a way that the film shall have a perfectly even thickness throughout; to turn out a great number of plates or films at the rapid rate necessary to make such a business profitable; to keep everything quite free from dust and dirt; and to do this with no light to help you except a feeble glimmer that comes through the

deep red globe of an electric lamp—well, that's a quite different matter.

In order to acquaint myself with the process of manufacture, I visited the establishment of Messrs. J. B. Edwards and Co. at Ealing.

The glass plates are imported from Belgium, ready cut to certain sizes. They stand piled by thousands in the storeroom. When a plate's turn for being coated comes, it has first to be thoroughly well scrubbed and given an application of a "substratum," which helps the sensitive film to adhere to its smooth surface. The two operations are performed by an ingenious machine worthy of special notice. If you consult Fig. 60 you will be able to follow this description of its working. A man at A pushes the plates vertically into the machine on to a travelling belt running on rollers, two of which can be seen under the plates. A row of glass balls in sockets near the top edge of the plates allows the operative to press a plate sideways quickly into the runway, the balls rising to let the plate pass, and falling behind it. The belt carries the plate forward into the next part of the apparatus, a glass-sided box provided with vertical rollers, the rubber rings of which catch the plate and move it on to another roller, studded

with stiff bristles arranged spirally, and revolving 600 times a minute. This scrubs one side of the plate, and most of the dirt that it detaches is carried off by a stream of clean water flowing constantly through this part of the machine. The other side

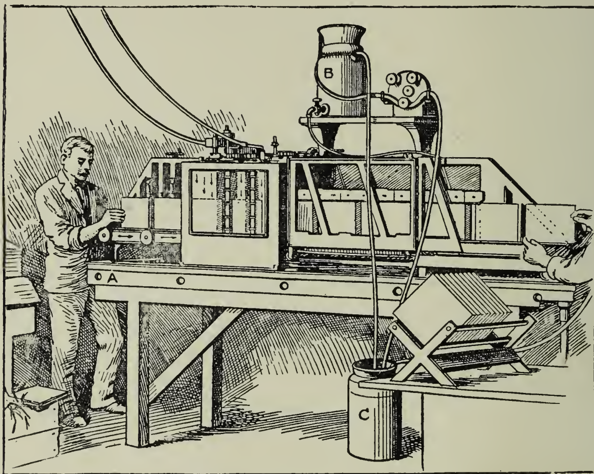


Fig. 60.—A Glass-Plate Cleaning and Coating Machine.

is treated similarly after the plate has progressed a short distance. The glass sides prevent the brushes from flinging water all over the room, and allow the plates to be watched during their progress.

The scrubbing finished, the plates move out of the closed compartment, and pass under pipes which squirt

water downwards through a multitude of small holes. The water, being divided by the top edge of the plate, flows evenly down both faces, and rinses off any particles of dirt that may have been detached, but not removed, in the scrubbing-chamber. The substratum is applied in the same manner, descending from a jar B through a rubber tube to the point of overflow. All surplus liquid runs through another tube into jar C, whence it is pumped by the little device at D back into B, which filters it and renders it fit for further use. D is a very simple form of pump, designed by Mr. Edwards to avoid bringing the substratum into contact with any metallic surfaces. A rotating disc *a* carries on one face near the circumference three projecting rollers *bbb*. The tube *c*, made of the purest and softest rubber obtainable, is pressed hard by each roller in turn against a curved metal support, and its contents are pushed forward towards the upper jar, while fresh liquid rushes from the lower jar into the vacuum behind the point of squeezing. The rubber pump tube has to be renewed after from six to eight weeks' use (Fig. 61).

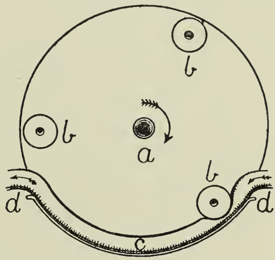


FIG. 61.—A simple Pump.

After receiving their coating of substratum, the plates are dried in racks, and carefully examined for defects. Those that pass the inspection are transferred to the coating-room proper. Another diagram is needed (Fig. 62) to explain what happens to them there. They are laid, touching one another, on a travelling band *a*, which carries them towards the left. Roller *c*, revolving in a bath of film emulsion kept liquid by heat, scrapes against an apron *d*, down which a thin, even sheet of the substance flows con-

FIG. 62.—Machine for coating Glass Plates with sensitized emulsion.

tinually on to the glass plates moving below. Belt *b* runs a little faster than *a*, and consequently, as soon as more than half the weight of a plate rests on it, that plate is separated from its successor—an easy matter at this stage, since the film is still liquid. By the aid of the dull ruby light the visitor is just able to distinguish the white procession of coated plates as they glide at the rate of about twenty a minute from under the "coater." It strikes him as rather remarkable that an amount of illumination decidedly

less than what he is accustomed to in his own dark room should suffice for the most important stages of plate manufacture. But the makers cannot afford to run any risks, and these plates, being isochromatic, are sensitive even to a strong red light. Furthermore, the workmen appear to be quite at their ease in the semi-darkness.

Above belt *b*, and close to it, is an ice-box *e* (Fig. 62). This cools and sets the emulsion. As fast as the plates reach the end of *b* they are lifted off by a boy and placed in racks, which, when filled, go to the drying-rooms. After a two days' exposure to the hot air of these compartments, and after being smeared at the back with an anti-halation coating, the plates are ready for cutting into smaller sizes, if necessary, and packing.

About the last nothing need be said. The cutting is done mechanically by passing the plate, film side upwards, between a roller above and a diamond point below. A guide ensures that one edge shall run at a constant distance from the diamond. I saw plates being scratched once lengthways and twice crossways by the cutter, to divide them into six lantern slides each, an operation which occupied far less time than it takes to write about it.

I should mention here that very large plates are not coated in the manner described, but are flooded separately with emulsion by hand. The workman, after pouring out sufficient emulsion from a teapot to form a little pool in the centre, rocks the plate in such a way as to distribute the coat equally over all parts, and drains off the surplus at one corner. The process is exactly similar to that of "varnishing" a negative, with which some of my readers are no doubt familiar.

In conclusion, films, whether of the "roll" or "flat" variety, are treated mechanically like small plates, the long strips of celluloid being cut up into the requisite sizes after passing through the coating-machine.

Chapter X.

THE MECHANISM OF WEAVING.

Warp and weft—Simple weaving—An improvement in method—The hand-loom—Healds—The reed—Shooting the shuttle—Twill weaving—The dobby loom—The Jacquard loom—Its principle—A wonderful device—The drop box—The power-loom—The Northrop loom.

AS the machines used for weaving cotton, wool, linen, jute, silk, and other textile fabrics have certain mechanical principles in common, it will be advisable to devote a chapter to a short examination of the functions that a loom performs.

A woven fabric is made up of two elements—the *warp*, or longitudinal threads; and the *weft*, or cross threads.

In Fig. 63 we have six flat tapes A A A, B B B, which constitute a warp, and a tape C for the weft. Imagine that, in the first instance, all six tapes are attached at both ends to a frame. In order to interweave the weft, it is, during the first "pick," or cross-

ing, passed over A A A and under B B B; and during the second pick, over B B B and under A A A. All the "odd" picks repeat the first, all the "even" picks the second.

Such a process is very tedious. Could we not hasten matters a bit? Well, suppose that we free the A A A part of the warp at the right-hand end

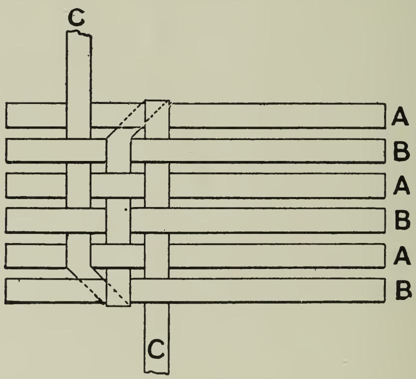


FIG. 63.—Diagram to show principle of Weaving.

and attach the three tapes to a big comb with three long teeth, by moving which we can raise A A A above or depress them below B B B. Starting afresh, we take our tape C, which for convenience' sake has now been wound on a needle, and depress A A A. It is very easy to push the needle across above A A A and below B B B. Before the return stroke we raise

A A A with the comb, so that the needle may pass over B B B and under A A A.

The threads of the weft, owing to the width of the needle, cannot be made to lie close to one another as they are "picked." But we can easily push each pick up against its predecessor with the teeth of a comb inserted between the strands of the warp.

Our system is, of course, extremely crude, though it includes the three primary operations performed by every loom, from the hand machine of the cottager to the latest mechanical device used in the factory.

These operations are: (1) Opening the "shed" (Ger. *scheiden*, "to part") in the warp, some threads being raised ready for (2) "picking" the weft through the shed; (3) "beating up" the weft.

THE HAND-LOOM.

A power-loom is a very complicated piece of machinery, and it would be difficult to explain its action by means of diagrams. So we will content ourselves with an examination of the now almost obsolete hand-loom, which contains in a simple form all the necessary parts of a weaving-machine.

Fig. 64 is a diagram of such a loom. The warp

threads are unwound from the roller (known in the trade as a "weaver's beam"), passed between two flat "lease rods" M, through the "healds" B B and the

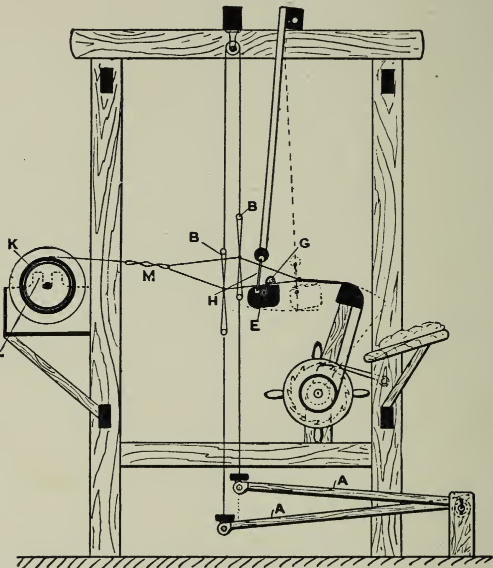


FIG. 64.—Diagram of Hand-loom.

"reed" H, and on to a taking-up roller at the weaver's end of the loom.

The "healds" will be understood by the help of Fig. 65. Each heald consists of two flat wooden shafts slightly longer than the width of the cloth required, connected by a number of vertical wires or

threads (leashes) with eyes, or "mails," at the centre.* The healds are attached to the pedals and also to one another by cords, in such a manner that the depression of a pedal raises one heald and pulls the other down. One thread, or "end," of the warp is threaded

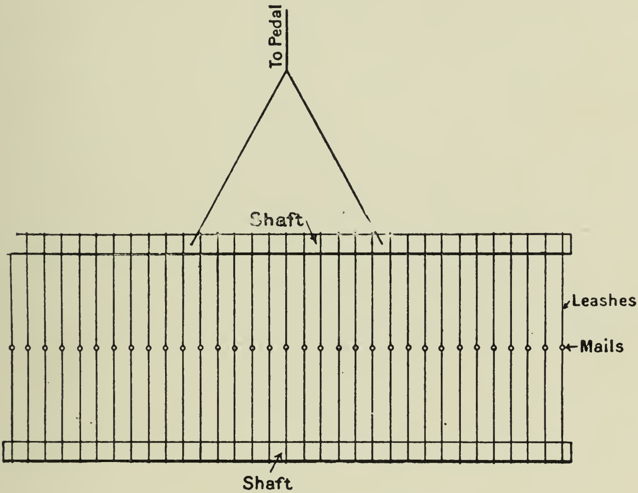


Fig. 65.—A Heald for a Loom.

through each eye—all the even ends being assigned to one heald, all the odd ends to the other.

The ends then pass through the "splits" in a "reed"

* Each leash and its mail, if working independently of the rest, would become a heald; and some writers therefore term a heald of the kind described as a "shaft of healds." For convenience' sake we will here assume the word "heald" to signify the two heald shafts and all the leashes attached.

(Fig. 66), which swings backwards and forwards on a frame, and carries on its lower edge a shelf E, the "sley," with a shuttle-box at each end (Fig. 64). The reed beats up the weft after every pick, when pulled forward into the position indicated by the dotted lines. The sley serves as a support for the shuttle G, which carries the weft inside it, and is jerked from one side of the loom to the other by means of a "picking-stick" working above the shuttle-boxes.

After this preliminary survey of the apparatus, we

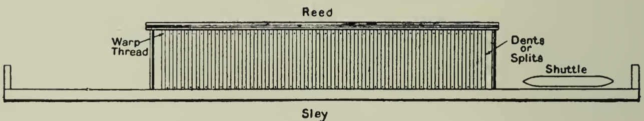


FIG. 66.—Showing a Reed, Shuttle, and "Sley."

will watch a weaver at work. He receives his beam from the spinners ready wound. The first thing he has to do is to pass the ends of the warp between the lease rods M, then separately and alternately through the healds, then through the reed, one or more through each split; and to attach them to the taking-off reel, which can be rotated by means of short projecting handles.

Everything being ready, the weaver takes his seat and pushes a pedal down. The "shed" opens, in a

lozenge form, as shown in Fig. 64. With a jerk of his picking-stick the shuttle is shot across over the threads held down by the lower heald. The reed and sley are then pulled forward, driving the first pick of the weft before it. While they return, the weaver depresses the other pedal, and the shed is made again,

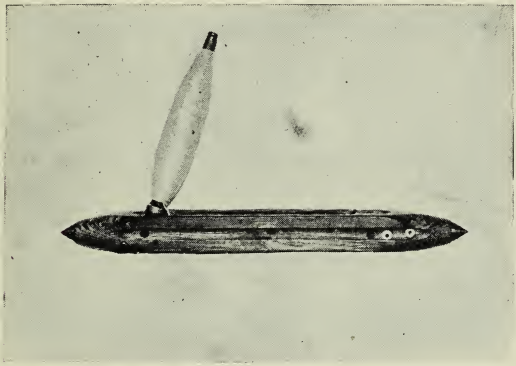


Fig. 67.—Shuttle and "Cop" of Cotton Thread. The end of the thread is drawn through one of the white eyelets at the right end.

its forward angle now being at the first pick, which prevents the threads from crossing beyond it. The shuttle is jerked across, and the reed comes forward again, beating up the second pick against the first. In this manner the "length" of cotton, linen, or woollen cloth is made. The closeness of its texture depends on the number of warp and weft threads to the inch.

(Fine cotton cloth has as many as 125 or more threads to the inch in both warp and weft.)

The process described is *plain* weaving, with the weft crossing alternate warp ends, and employs two healds only. If the number of healds be increased more or less complex patterns become possible.

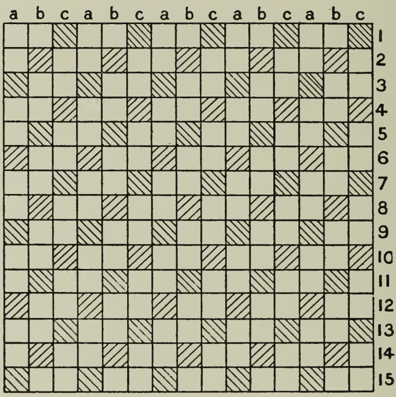


FIG. 68.—Diagram to show the principle of Twill Weaving.

A simple three-leaf "twill" can be produced with three healds, worked by three separate pedals. Fig. 68 shows how it is managed. All the *a a a*, *b b b*, and *c c c* threads of the warp are controlled by their respective healds. For picks 1, 4, 7, 10, 13, the *a* and *b* healds are lifted, so that the weft (indicated by the shaded parts) shows only between the *a* and the *b*

threads of the warp. For picks 2, 5, 8, 11, 14, *a* and *c* healds are raised; and for picks 3, 6, 9, 12, 15, the *b* and *c* healds. On the top side the warp preponderates, on the lower side the weft.

For the weaving of very intricate figures the warp must be divided among a very large number of healds, and in extreme instances every thread of the warp may have its separate lifting apparatus. In order to preserve the pattern while working at a high speed, some automatic mechanism for lifting the warp is needed. A comparatively simple form of self-acting, shed-forming device is the "dobby," shown in Fig. 69. The reader is supposed to be looking along the loom in the direction of the warp. The healds C are connected in groups to heald pins B, which normally have their upper hooks over a knife beam A, which rises every time before the shuttle is shot. At one side of the loom is a roller D, from which project rows of pegs E E E. In each row there is room for as many pegs as there are heald hooks, which number, perhaps,

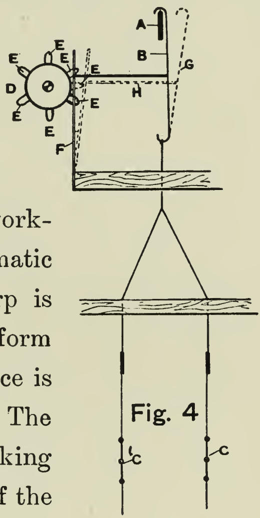


FIG. 69.
Lifting Mechanism of "Dobby" Loom.

a dozen or more. The pegs are arranged differently in each row. When a peg meets a heald pin spring F, it pushes it back into the position indicated by the dotted lines, and prevents that pin from being raised the next time the knife beam ascends, so that all the warp threads operated through that particular pin come *under* the shuttle during the following pick. The advantage of the dobby is that the pattern can be altered by merely shifting the position of the pegs in their respective rows, or by reducing or adding to their number.

Far more ingenious than the dobby is the

JACQUARD LOOM,

which has immensely widened the field of weaving. Its principle is illustrated by Fig. 70. The pins P P, each of which lifts one or more threads of the warp, are pivoted on horizontal rods R R. One end of each rod passes into a spring box B, in which a small spring keeps a button on the rod pressed up against the nearest side of the box. The other end passes through a perforated board G, called the "needle board," and projects outwards a quarter of an inch.

In the ordinary Jacquard loom there are eight tiers of these rods, and fifty rods to each tier, giving a total

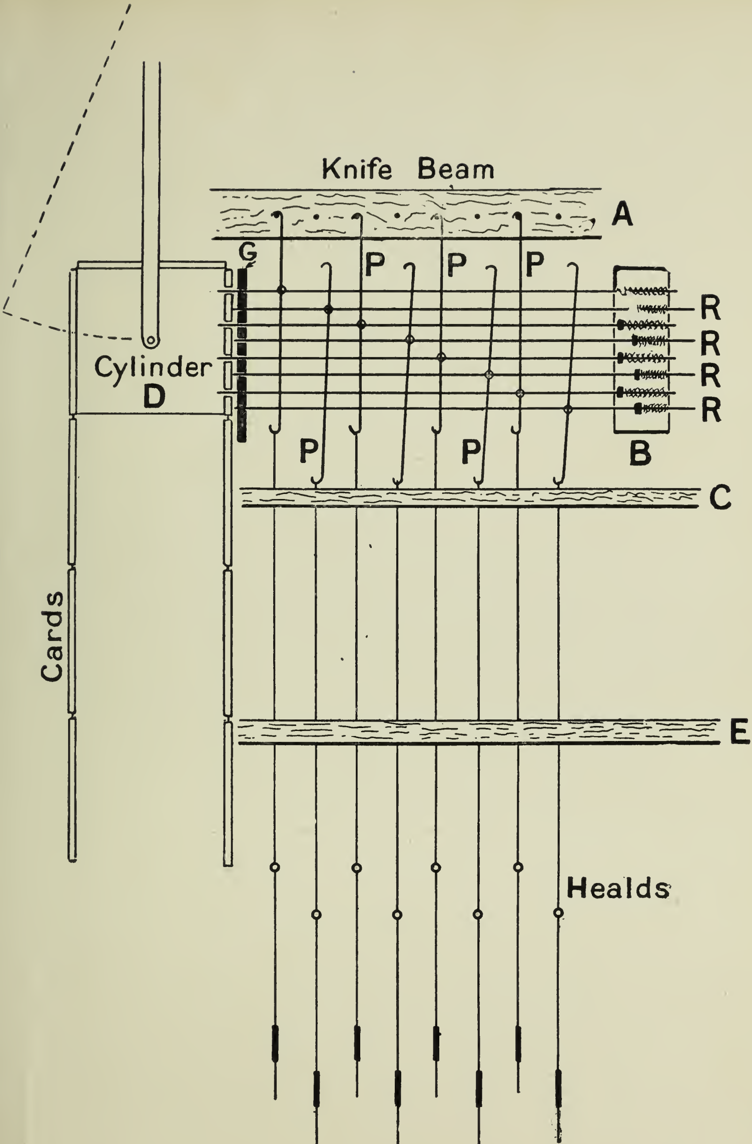


Fig. 70.—Diagram of the Jacquard Loom.

of four hundred. The heald hooks of each tier are lifted by one blade of an eight-bladed knife beam, so that if all the hooks were in their normal position they would be lifted simultaneously. But before every pick of the shuttle a square "cylinder" D is swung up against the projecting ends of R R. This cylinder revolves on pivots, and its function is to press in succession each of an endless band of long, narrow cards against the points of R R. The cards are perforated with a large number of holes arranged in eight rows of fifty each. Now, when the card is pressed up by the cylinder, wherever there is a hole it passes over the end of its corresponding rod, and that rod and its pin is not moved. Consequently, when the knife beam ascends the pin is raised. But wherever holes have not been pierced, the rods are driven in against their springs by the card, and the heald pins are thrown out of action.

For each formation of the "shed" a separate card comes into play until the circle of the cards is complete, and the pattern then begins to repeat itself. Instances have been known in which the enormous number of over ten thousand cards were used in the production of one pattern. Jacquard looms are made with as many as one thousand or more heald pins, which

allows such a variety of combinations in the punching of the cylinder cards that, in the same manner as the paper roll of a mechanical piano player can be pierced to produce any required tune, the Jacquard cards can be perforated for the most elaborate pictures in silk, cotton, linen, etc. Even so long ago as 1840 there was exhibited at Leeds a beautifully distinct facsimile of the will of Louis the Sixteenth, entirely woven by the Jacquard machine. Since then its powers have been greatly developed, so that there is no saying of what it is not now capable.

THE DROP, OR CIRCULAR, BOX

is a device for changing shuttles automatically, where two or more colours are used in the weft. The shuttles are arranged in a kind of revolving cage, actuated by pins on an endless belt, which shifts a shuttle of the colour required into position for being shot when its turn comes. The drop box, in combination with the Jacquard loom, has much facilitated the weaving of ribbons and "figured" textiles of all sorts.

THE POWER-LOOM,

while embodying the chief features of the hand-loom, is, by reason of its automatic nature, much more cer-

tain and rapid in its action. The Northrop loom, now used so largely for the weaving of cotton cloth, has an automatic arrangement for supplying the shuttle with a fresh "cop" of weft yarn when required. If the weft breaks, the bobbin may be immediately expelled and replaced without any stoppage of the loom,

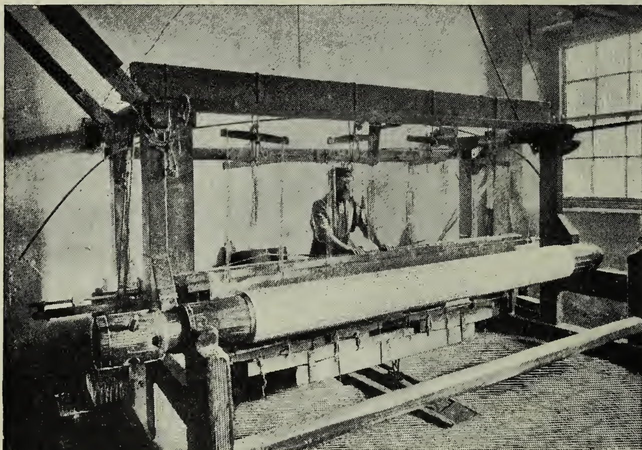


Fig. 71.—A Hand-loom Weaver at work on cloth 150 inches wide.

though this is not done where perfect cloth is required. Among other interesting features of this loom is a device for stopping the machinery instantaneously if a thread in the warp breaks. So perfect is the action of the Northrop that one weaver can superintend twenty-four looms.

Chapter XI.

THE MANUFACTURE OF COTTON GOODS.

The value of cotton—The magnitude of the cotton industry—Where raw cotton comes from—Lancashire the seat of British cotton manufacture—The cotton crop—Separating the cotton from the seed—Gins—In a cotton-mill—Breaking the bales—The cleaning-room—Carding—Drawing—Slubbing—Spinning—The ring frame—A spinning-mule—Preparing the warp—Drawing the warp into the healds and reeds—Twisting-in—In the weaving-shed—Singeing—Finishing—Bleaching—Calico printing.

A PROMINENT English statesman once said at a great public meeting, "There is not a single civilized man in the world who does not want cotton goods. I don't care who he is or where he is, how he lives or what he does, every man wants cotton goods in some shape or form." The great novelist, Sir Walter Besant, has written with equal emphasis in praise of cotton: "The first step in the elevation of the lower classes was the introduction of cotton fabrics which could be washed......Civilization, in fact, largely depends upon the possibility of

wearing cheap garments which can be washed." Nor is the demand for cotton goods confined to civilized nations, for we all know well enough that cotton cloth finds a ready market among the more or less barbarous races of Africa, America, and Asia.

The magnitude of the cotton industry may be estimated from the fact that the British Isles *exported* cotton goods in 1904 to the value of £74,000,000, a sum equal to one-quarter of that received for the total exports of the year. Allowing for the home market, which equals at least one-third of the export trade, the cotton spinners and weavers of the British Isles convert raw cotton into goods worth £100,000,000 annually.

For the raw cotton Great Britain pays about £50,000,000 every year. Five-sixths of the supply comes from the United States, the bulk of the remaining one-sixth from India and Egypt. A rapidly-increasing quantity is now produced in our African colonies. Though cotton grows in all tropical and subtropical countries where a light soil, a high temperature, and a heavy rainfall occur together, the conditions are peculiarly favourable in Alabama, Arkansas, Georgia, Louisiana, Mississippi, the Carolinas. and Texas; and for many years to come these

states will provide the bulk of the raw material for British and American cotton goods.

That Lancashire should be the chief centre of cotton manufacturing is not due to chance or circumstance so much as to climate. A certain moisture in the air makes it possible to spin finer and stronger cotton yarn in Lancashire than in any other part of the world, and also greatly assists the weaving of yarn into cloth. South Lancashire and North Cheshire are the chief strongholds of the spinner, whereas weaving is mostly confined to the large towns in the northern half of Lancashire, though in some of the largest mills both spinning and weaving are done.

THE COTTON PLANT

is produced from seed sown in spring. In June the young plants bloom with a flower somewhat resembling that of the hollyhock. The flower soon falls off and the seed-pod begins to form. By August the pods are ripe and burst open, disclosing a number of seeds enveloped in a white downy substance, which expands rapidly into a soft ball or beard. Until the early frosts appear, all hands on a cotton plantation are busy gathering seeds and

down in baskets, and spreading them to dry in the sun. When dry, the material is passed through a gin, which separates the cotton from the seed. The saw gin (Fig. 72) is most commonly used in America. It consists of two groups of fine-toothed circular saws *a a*, revolving with part of their circumference projecting through a grid *b* into the hopper *c* containing raw cotton. The saws catch the cotton and drag it through the grid, and a roller armed with brushes pulls it from the saws and shoots it out through an opening. The seeds, being too large and smooth for the saws to take hold of, are left behind in the hopper, from which they escape through a slit in the bottom, and are collected to make into cake for feeding cattle with.

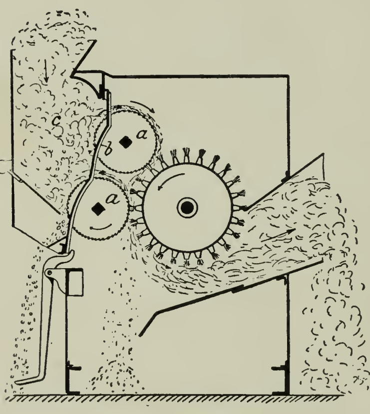


Fig. 72.—A Saw Gin.

For fine varieties of cotton the roller gin (Fig. 73) is preferred. The cotton from the hoppers passes between leather-faced rollers, which squeeze out the

seeds and retain the cotton until it reaches a point where knives scrape it off.

The ginned cotton is then placed in a hydraulic press and made up into bales of 480 lbs. each, bound round with thin hoop iron. In this state it is shipped to England.

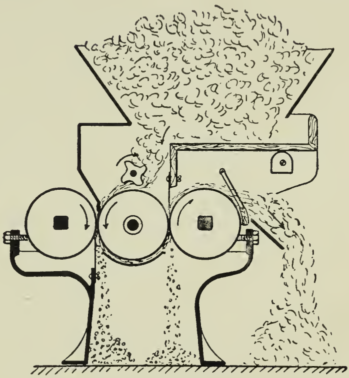


FIG. 73.—A Roller Gin.

IN A COTTON-MILL.

"No more than a visit to a cotton-mill and a survey of the thousand processes by which all varieties of cloth—strong and sternly-simple calico, or fabrics beautifully and delicately woven in artistic patterns—are brought forth from the fluffy, fibrous, tangled mass of crude cotton is needed to lose the hackneyed conception of the littleness of man. The majesty and overwhelming force of the engine-room is the ratio of his might. It is stupendous that his brain should have planned and his small hands have made the giant driving-wheel which would overtop a house, and fashioned the engines which set it whirring to drive

the countless scutchers, drawing-frames, carding-engines, spinning-mules, and frames and looms which throb and grind throughout the many floors of the mill. Great as is this realization of the masterfulness of man, a deeper significance comes from its detailed purpose as seen and watched in the untiring precision, the almost conscious action, and the transforming, changing, creating force of these pulleys and cog-wheels and shaftings, bobbins, spindles, shuttles, and rollers." These eloquent words of a writer in the *Times* well express the feelings of any one who has explored a big mill with a mind sensitive to new impressions, and has watched the gradual conversion of bales of raw cotton into finished cloth ready for the bleacher. In the following description of the many processes through which the raw material has to pass, I shall endeavour to give the reader a fair idea of the industry in which hundreds of thousands of Lancashire folk are busied for five and a half days in the week.

On entering a mill, the cotton is transferred to the mixing department, where men armed with axes cut the iron hoops confining the bales. Lumps of cotton of different grades are torn from their respective bales and thrown into the hopper of a *bale-*

breaker (Fig. 74), and carried through a series of spiked rollers revolving at different speeds so as to

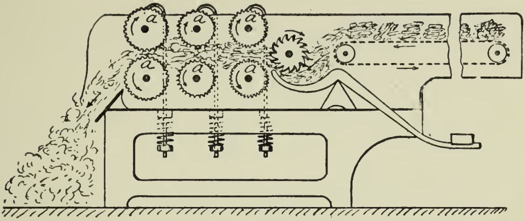


FIG. 74.—A Bale-breaker.

tear the cotton apart. As it emerges it is caught on a travelling lattice and flung down a shoot into

THE CLEANING-ROOM,

and subjected to the blows of steel blades revolving from 700 to 1,000 times a minute. The lumps and tangles are broken up, and dust, seed, husks, and dirt are expelled through gratings. After leaving the *opening machine*, in which this happens, it enters a *scutcher*, which further cleanses it and rolls it out into a thick sheet or "lap" of "cotton-wool," which is wound up on large reels.

CARDING.

If a piece of cotton-wool be viewed through a microscope, it is seen to be composed of a number

of fibres, each about $\frac{1}{2000}$ of an inch in diameter, and resembling a flat twisted ribbon with tiny teeth along the edges. The fibres lie in all directions, and before the cotton can be spun into thread it is necessary to straighten the fibres into line, so that

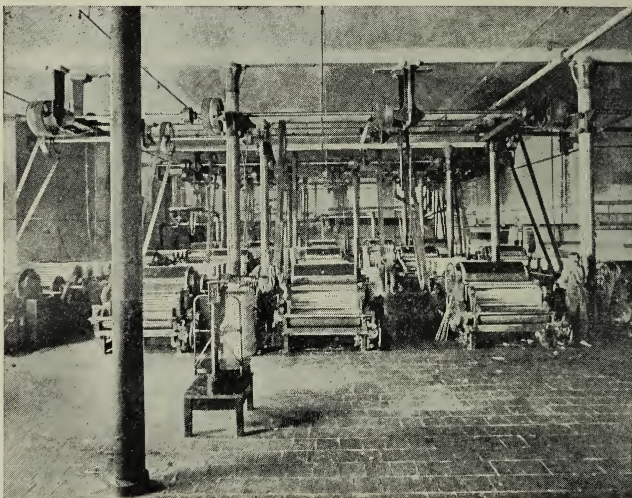


Fig. 75.—A Scutching-machine.

they may catch hold of each other when twisted together.

The *carding-machine* does two things—(1) it gives the cotton a further cleansing; (2) it begins to straighten out the fibres. Fig. 76 is an illustration of a flat carding-machine. The roll of finished

"lap" from the scutcher is mounted at C, and passed under rollers which feed it up to the "taker-in" D, a cylinder covered with sawlike teeth. These flick off pieces from the end of the lap on to the face of the big cylinder B, which bristles with wires set 600 to the square inch—totalling some 4,000,000 on the cylinder. An endless band of "flats" A, also

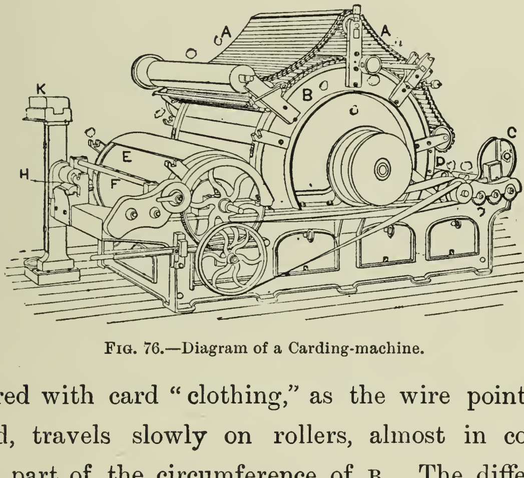


FIG. 76.—Diagram of a Carding-machine.

covered with card "clothing," as the wire points are called, travels slowly on rollers, almost in contact with part of the circumference of B. The difference between the speeds of the flats and the cylinder separates the cotton fibre by fibre, and lays it in parallel order. From the carding cylinder the cotton issues as a veil of ordered cotton $\frac{1}{100}$ of an inch thick, which is detached from the cylinder by a "doffer

roll" E, and lifted from the doffer by a "doffer comb" F. The web is drawn through a narrow tube and compressed into a flat ribbon about one inch wide and half an inch thick, known as "sliver;" and so the

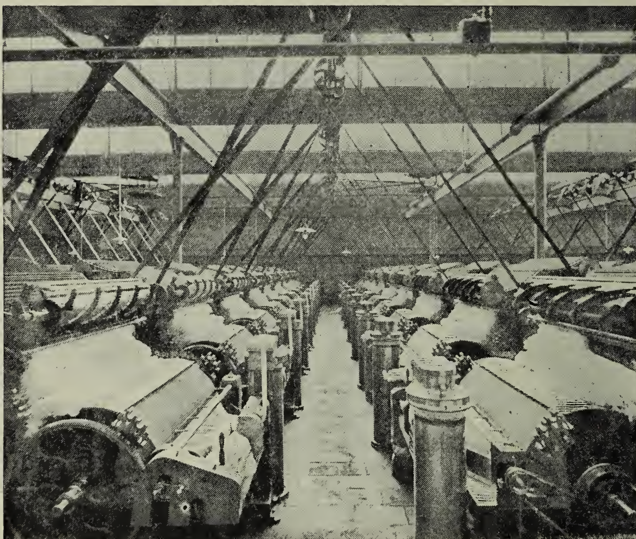


Fig. 77.—View of a Carding-room.

first important step towards the formation of thread has been achieved.

DRAWING.

The next process is to lengthen the slivers on a *drawing-machine.* They are passed in groups of

six through three sets of rollers moving at different speeds, the front set six times as fast as the back (Fig. 78). Consequently each sliver is reduced to one-sixth of its original thickness; but inasmuch as six slivers are combined by the drawing-machine,

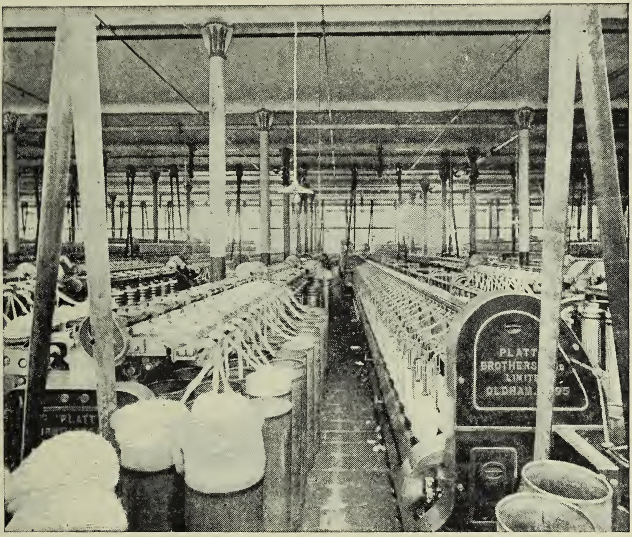


FIG. 78.—Drawing-machines at work.

the slivers that emerge are of the same thickness as those which enter, though six times less numerous.

Six slivers from the first drawing-machine are passed through a second machine, and those from the second through a third machine. At the end of

the drawing 6 × 6 × 6 = 216 original slivers have been grouped together and correspondingly lengthened, while the fibres have been arranged in a more exactly parallel order.

A most ingenious automatic check action is employed on the drawing-machines. All the top rollers (A, B, C) form one terminal of an electric circuit, all the bottom

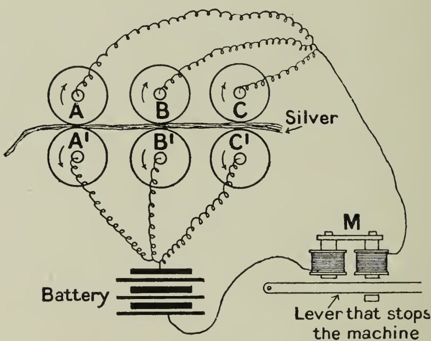


Fig. 79.—Automatic Electric Stop Action.

rollers (A^1, B^1, C^1) the other terminal. If a sliver breaks the top roller falls against the bottom, the magnet M attracts a lever, and the machinery stops (Fig. 79).

PRELIMINARY TWISTING AND WINDING.

The slivers now go through the *slubbing-frame* (Fig. 80), which draws each one out to several times its original length and winds it on to a bobbin, and

while doing so gives it a slight twist. The standard frame carries ninety bobbins and treats as many slivers.

The *intermediate frame* lays the threads from two slubbing-bobbins together, draws them out finer, and twists them further. The intermediate bobbins are placed on a *roving-frame*, and two threads are treated again in the same manner. In some cases a *jack frame* repeats the process a third time.

The working principle of all these machines is the same throughout. Three pairs of rollers *b b b* (Fig. 80), moving at different speeds, extend the thread, which passes to the top of a "flyer" *d*, down through a hollow arm to the end, and on to the bobbin. Great ingenuity has been expended on solving the various problems arising from the following facts:—(1.) That though the thread is delivered from the rollers at a uniform rate, the amount of thread taken on the receiving bobbin at every revolution must increase as the diameter of the coils increase. (2.) That if the flyer revolved at the same speed as the

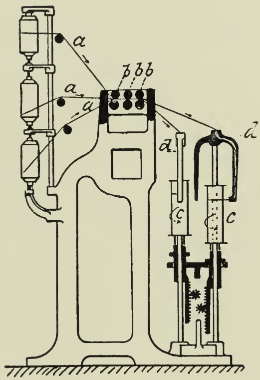


Fig. 80.—Slubbing-frame.

bobbin, the thread would receive a twist, but no winding on the bobbin could possibly take place. These two difficulties are overcome by making the flyer spindle revolve at a constant speed, and gearing the bobbin to it in such a manner that as the bobbin

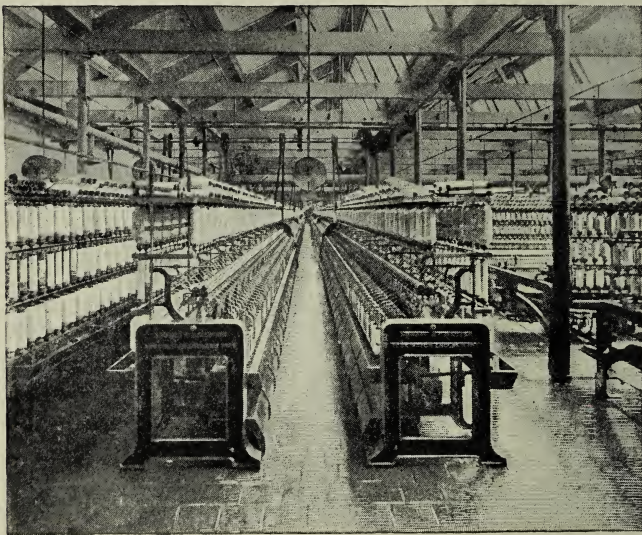


FIG. 81.—Roving-frames.

fills it revolves at a gradually decreasing speed as compared with the flyer spindle. (3.) That the bobbin must move up and down the flyer spindle, so that the thread may be wound evenly from one end of the bobbin to the other. (4.) That the build-

ing motion must be so adapted as to give the bobbin a taper at each end.

A description of the intricate mechanism employed would probably weary the reader, and he will no doubt be satisfied with the assurance that though, as already stated, a cotton-mill is full of the most wonderful machinery, the slubbing, intermediate, and roving frames afford peculiarly notable examples of human ingenuity.

SPINNING.

When it leaves the roving-frame the material of a sliver has been converted into a coarse and slightly-twisted thread. Before it is fit for use in the loom it must be reduced and twisted many times. Warp yarns are usually spun on a *ring frame*, in which the spindles on which the bobbins are placed revolve inside a ring B (Fig. 83) having a recessed rim or lip. A small curved piece of steel wire A, called a "traveller," is sprung over this rim, around the circumference of which it can move freely. The thread, after being drawn out by rollers in the usual manner, passes through this ring on to the bobbin; and as the traveller, on account of friction against the ring, runs round somewhat slower than the spindle revolves, the thread is wound on to the bobbin, being

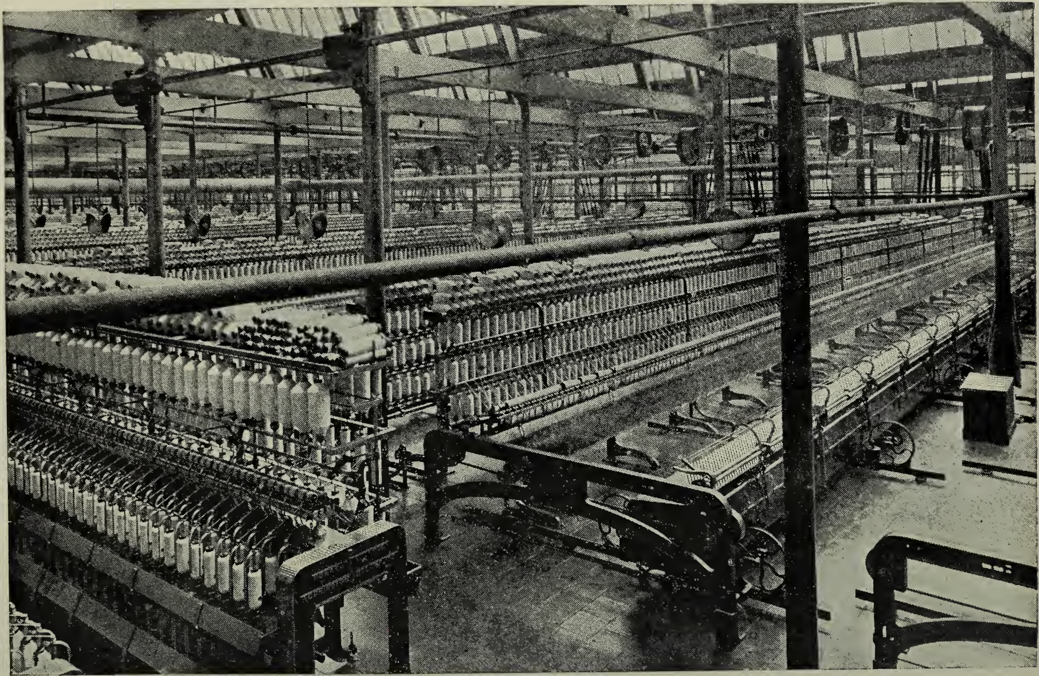


Fig. 82.—General View of Spinning-room.

twisted meanwhile by the rapid revolution of the bobbin, which attains a speed of 8,000 or more revolutions a minute. An up-and-down movement of the rail C, in which the rings are set, allows the thread to be wound evenly from end to end of the bobbin.

For the weft, which is softer than the warp—and sometimes for the warp as well—the *self-acting mule* is more generally used. The mule occupies a space ranging up to 200 feet broad, by about 12 feet from front to back.

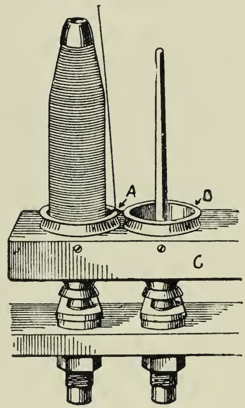


FIG. 83.—Diagram of Ring Spinner.

Bobbins of soft "rovings" A A (Fig. 84) from the roving-frame are set up on creels along the back edge of a roller beam. Each roving passes through a guide-plate C, between the drawing-rollers D, over the arm M, under the arm L, and on to a spindle E mounted on a movable carriage K, which is the full breadth of the mule, and may hold upwards of twelve hundred spindles driven off a long tin roller H.

The series of operations repeated by the mule every few seconds are as follows:—

(1.) The carriage is pushed up as near as it will go to the roller beam.

(2.) It retreats slowly from the beam, drawing the yarn rather faster than the rollers D deliver it, so as to keep it taut. The spindles meanwhile are revolving several thousand times a minute, and twisting the yarn without gathering it.

(3.) On reaching the limit of its travel—about $5\frac{1}{2}$ feet—the carriage stops, and the rollers D cease to give out yarn.

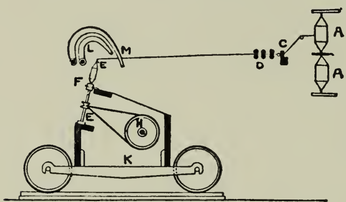


FIG. 84.—Diagram of Spinning-mule.

(4.) The spindles are reversed, to throw off the coils that have worked up towards the end of the bobbins. M rises and L falls, to take up the "slack" and keep the tension even.

(5.) The carriage begins to move towards the beam, and the spindles, reversed again so as to run in their original direction, wind the twisted yarn on to the spindle bobbins.

This is repeated until the "cops," as the spools of thread on the spindles are called, have attained their full size, when they are removed from the spindles and the process begins again.

All movements are automatic; the attendants have merely to remove the cops and piece-up any threads that may break.

A 1,200-spindle mule draws, twists, and winds on, in the case of medium "counts," about 7 miles of thread a minute, or about 3,000 miles in a working day of eight hours.

The fineness of a thread is denoted in "counts." A hank is 840 yards of thread. A 32-thread signifies one which runs 32 hanks to the pound of 16 oz. American cotton can be spun 38 miles and Egyptian 95 miles to the pound, and experiments have proved that it is even possible to produce yarn so fine as 1,000 miles to the pound.

PREPARING THE WARP.

Warp thread is wound from ring bobbins or mule cops on to large bobbins, some five hundred of which are placed in a V-shaped creel and the ends threaded through combs and rollers to a circular wooden beam. The sheet of threads is wound on to the beam, sometimes to a length of 20 miles. An automatic stop action arrests the machinery if a single thread breaks.*

* The attendant on a winding-frame in many modern mills has strapped to one hand a wonderful little "knotter," which knots together two ends drawn through it and cuts off the ends close to the knot, so that a break can be repaired in a moment.

Each thread supports and slides through a piece of wire bent like a hairpin. If any thread parts, the wire falls between two rollers and instantly stops the machine.

When the proper length of yarn has been wound on to the beams, several of them are placed in a *sizing-frame* and unwound on to a weaver's beam. While passing from one beam to the other they go through a trough containing a boiling mixture of sago or flour, which lays any protruding fibres flat and toughens the exterior of the thread, and are subsequently squeezed by rollers and dried by steam-heated cylinders. As the warp approaches the beam it is marked at the length required for a "piece" by a hammer which descends automatically. The tough threads for the edges, or selvedges, are simultaneously wound on to the beam from special bobbins.

When the beam is full, a comb is passed through the warp to keep the threads straight and parallel, and the threads are severed.

DRAWING-IN AND TWISTING-IN.

The beam now goes to a special department for the warp ends to be either (1) threaded through a set of healds and a reed, or (2) to be attached to

the ends of an old warp already threaded. The first process is performed by children, who with small hooks draw each thread separately through a heald eye, and two or more threads through each split in the reed. The healds determine the number of threads to each inch in the reed and the breadth of the cloth, and also decide, as described above (p. 146), the particular manner in which the weft shall interweave with the warp as the shuttle is shot across.

Twisting-in is performed by taking an end of a loom thread and the end of an old warp thread, twisting them together for an inch or so, and then twisting the double end round one of the threads. An expert hand joins the ends up very quickly by one rolling movement of the thumb and a finger. The beam is then ready for the loom.

IN THE WEAVING-SHED.

The spinning-rooms are noisy with the steady hum of thousands of spindles; a weaving-shed is even noisier with the racket of the looms, which are periodic in their action. The operatives, being unable to converse in spoken words, become adepts at "lip language," exaggerating with their lips the facial

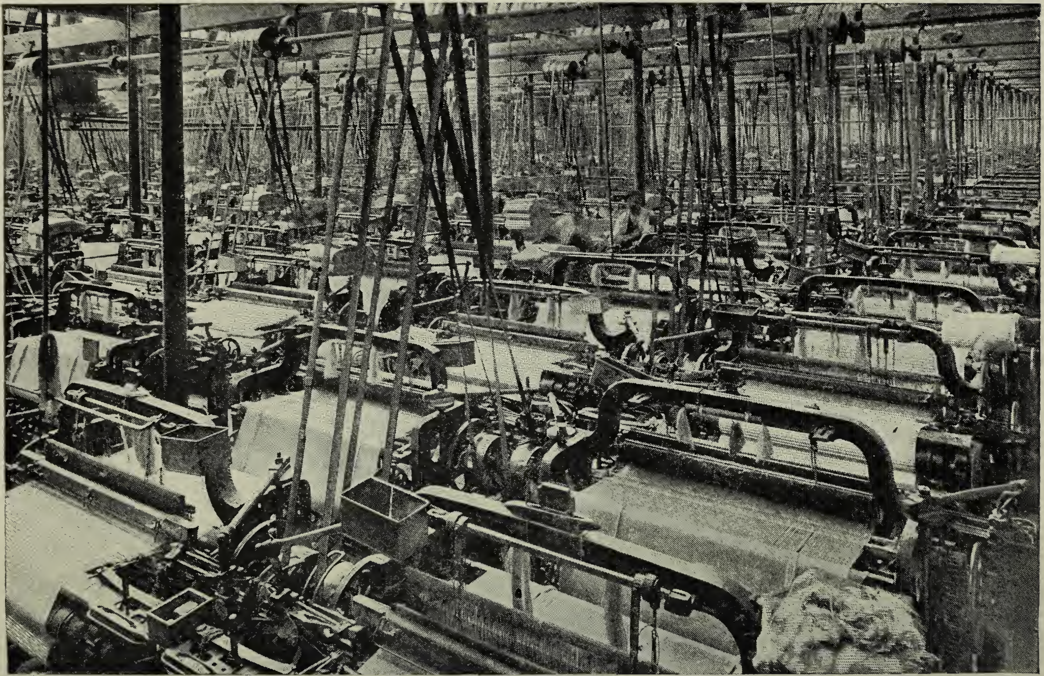


FIG. 85.—A Weaving-shed.

movements used in ordinary conversation. Without uttering a sound, they talk easily across the shed. In the light of this fact, it is curious that deaf people should be so averse to taking the trouble to learn, and their relatives and friends to teach, a method which would largely recompense both parties for the deafness of the one.

A weaving-shed is usually lit from the top, so that a strong light may be thrown down on the cloth and the warp. The looms are arranged in rows close together, with just enough room for a person to pass round them. A single shed may contain as many as two thousand looms. On each side of a loom the mechanical picking-sticks jerk backwards and forwards as they shoot the shuttle across the warp two hundred times a minute—so fast that the eye cannot watch it.

The reed beats up the last pick, the healds rise and sink, the beam is rotated an imperceptible fraction of an inch. Here is a weaver dexterously joining up a warp thread. There he is setting the pegs in a "dobby" loom to produce a simple pattern. We stop for a moment to watch the movements of a drop-box loom, which shoots white, red, and blue threads across the warp in a prearranged succession;

and presently we arrive at the Jacquard looms, with their wonderful overhead gear and punctured cards magically controlling the shed of the warp.

Then the Northrop loom, of which we have spoken (p. 152), arrests attention by the drum holding the magazine of "cops" for the shuttle. In some mills the operatives fill up the magazines and leave the looms working unattended while they are away at dinner. If a weft thread breaks, the cop in the shuttle is immediately changed, and the weaving goes on without interruption; if a warp thread parts, a pin falls and stops the machine, so that in neither case is any damage done.

According to the size of the loom, the width of the cloth varies from 16 to 140 or more inches. The piece measures on the average about 40 yards, and a piece of cotton cloth with 100 picks to the inch would occupy a loom for about twelve hours. The largest British firm, Messrs. Horrockses, Crewdson, and Co., owning seven thousand looms, produces over 30,000 *miles* of cotton cloth yearly—a quantity sufficient to girdle the earth at the Equator, and leave a surplus which would reach from the Cape to Cairo. The total exports of British cotton cloth for 1904 were 5,594 million yards, or about 3,000,000 miles.

Allow two miles of yarn to every square yard of cloth, and you will then understand why fifty million spindles are required in the spinning-mills of Lancashire.

As the principles of weaving have been described in the last chapter, we proceed at once to the later processes through which the cloth passes after it leaves the loom in what is known as its "gray" condition.

SINGEING.

The cloth is run over rollers which keep it in a state of tension, so that the nap, or surface hairs, may stand out from the fabric. These are all burned off by a row of bunsen burners over which the cloth travels. If the calico is to be sold unbleached, it is sent through a machine which registers its length and folds it up ready for market. But if it requires bleaching—that is, whitening—whether for subsequent printing or not, it goes from the loom to the bleaching works.

A number of "pieces" are there joined together end to end to form a continuous strip perhaps more than 20 miles long. It is singed by being drawn over hot cylinders. Then follow—(1) *Washing;* (2) *boiling* in lime-water under a steam pressure of

from 8 lbs. to 25 lbs. to the square inch; (3) *aciding* with sulphuric or hydrochloric acid; (4) *washing;* (5) *boiling* in a solution of soda-ash and resin; (6) *boiling* in a solution of soda-ash; (7) *washing;* (8) *bleaching* in a clear solution of bleaching-powder; (9) *washing;* (10) *souring* in sulphuric acid; (11) *washing;* (12) *squeezing;* (13) *opening*—that is, stretching along the weft; (14) *starching*, to improve the appearance and increase the weight of the cloth; (15) *drying*, by passing the cloth round cylinders heated with steam; (16) *damping;* (17) *beetling*—the cloth is pounded and softened by mechanically-worked wooden mallets which make five hundred or more blows a minute—or *calendering*, if a glazed finish is required, by rolling the cloth between smooth heated cylinders; (18) *folding;* (19) *pressing* in a Bramah press. The bleached cloth is then ready for the market.

CALICO PRINTING.

If the cloth is to be printed in colours, after process 13 it is—(1) passed through a printing-machine, which has a number of copper cylinders pressing against the circumference of a much larger central cylinder. Each of the smaller cylinders has that part of the design engraved on it for which it

has to supply the colour. The colouring matter is mixed with a "mordant," or chemical substance which enables it to grip the cloth. (2.) Steamed to fix the colours. Printed goods are starched, beetled, and calendered in the same manner as plain white bleached goods.

I should strongly advise any one who is given the chance of being shown over a cotton-mill to take it. By the courtesy of Messrs. Joshua Hoyle and Sons of Summerseat, Lancashire, I was enabled to make the acquaintance of an up-to-date spinning and weaving mill, and I can confidently say that what I saw there came as a revelation. The lightness of the "sheds," contrasting most favourably with the dark workshops of the "black" industries, the sense of well-ordered bustle, and the multiplicity of the moving parts—spindles, rollers, wheels—as compared with the fewness of the people who could control them—all these have left a deep impression on my mind, although it was at the time somewhat sated by explorations among the hives of industry.

[*Note.*—The author has to thank Messrs. Horrockses, Crewdson, & Co. for the photographic illustrations to this chapter.]

Chapter XII.

THE MANUFACTURE OF RUBBER GOODS.

Rubber—Its properties—Its value—Discovery by Europeans—The rubber tree—Collecting rubber—Scientific planting—Gutta-percha—The Silvertown Works—Cleaning raw rubber—Drying washed rubber—A clever device—Vulcanized rubber—Ebonite—Cable-making—The manufacture of tennis balls—Bottle-stoppers.

RUBBER, or to give it its full name, india-rubber (also called caoutchouc), is a very wonderful substance. It is elastic, and if prepared in a certain way will recover its original shape after an infinite number of distortions. It is tough. It will endure considerable heat and cold without being affected. It is a peculiarly bad conductor of electricity. "Of all substances it is the most obedient in manufacture. It can be dissolved and spread in a film $\frac{1}{1000}$ of an inch thick, and yet retain its properties and protect the wearer from the world's heaviest rain-storm. It can be made into a plastic mass, combined with other materials, just like baker's dough, and

squeezed into rods, tubes, or round cores of other material, or moulded into numberless forms and shapes; and all these, subjected to heat of a certain degree, become articles with a permanent form, losing their former plasticity, and, as the maker determines, either supple and elastic in various degrees or hard as ironwood. It can be moulded into a cylinder and cut into sheets of infinite fineness or into threads of various shapes. The puzzle is not so much what you can do with rubber, but what you cannot do with it."*

The value of rubber will be evident if you think for a few moments of the things in common use which have rubber in them—tennis balls, cycle and motor-car and carriage tyres, pipes of many kinds and sizes, waterproof fabrics, elastic bands, door silencers, draught excluders, football bladders, brake blocks, electric cables, etc. Wherever steam and electricity—especially the latter—are used as motive powers, rubber is required. Every railway train utilizes rubber for the brake gear; every Atlantic liner uses from £500 to £1,000 worth of the precious material. We say precious, because its price, owing mainly to the requirements of the motor-car and

* "Rubber Cultivation," page 16.

electrical industries, has risen very rapidly of late years, though the world's supply amounts to some 60,000 tons of raw rubber annually.

The first mention of rubber occurs in connection with the second voyage of Columbus, made more than four hundred years ago, when the Spaniards observed that the natives of Hayti played a game with balls fashioned out of the gum of a tree. These balls were light, and bounced much better than any of European manufacture. Not long afterwards the water-resisting property of rubber was discovered, and turned to practical use by the Spaniards, who smeared it over their cloaks to render them proof against the tropical rains. But rubber did not become an article of commerce until 1800; and yet thirty more years had to pass before Hancock, by his invention of the process named "vulcanization," firmly established rubber as a valuable industrial commodity.

There are many kinds of rubber-bearing plants, ranging in size from tall trees to small herbs. They require a hot, moist climate, and therefore grow to greatest perfection in tropical regions where there is a heavy rainfall. At present the chief source of supply is, as formerly, the huge basin of the Amazon, whence comes the Para rubber, gathered by Indians

from a forest tree known to botanists as *Hevea Braziliensis.*

The collector sallies out into the forest with a knife and a number of little cups made of clay or metal. On reaching a rubber tree he makes a long vertical cut in the bark, and to the bottom of it affixes a cup by means of a dab of clay. At intervals up the trunk oblique cuts are made leading into the vertical channel. A thin milky sap, called the "latex," oozes slowly from the gashes, and is guided by them into the cup, which the collector empties every morning into a pail. The latex contains a large proportion of water, and if exposed to the air for a long time in its raw condition would "go bad" and become useless. The Amazon natives dry and cure it by dipping into a vessel full of the fluid the head of a piece of wood shaped like a paddle, and revolving it over a smoky fire made from a particular kind of nut, which gives off gases that render harmless the fermentable elements of the latex. The operation is repeated until there is on the end of the paddle a ball of cured rubber as large as a man's head. The "mould" is extracted, and the ball is ready for export to the manufacturers.

This method of obtaining rubber becomes more arduous every year, since the collectors have to

penetrate farther and farther into the forests in quest of untapped or at least unspoilt trees; and consequently large plantations of Para rubber are now being made in Mexico, Central Africa, the East Indies, Ceylon, and especially in the Malay Peninsula. These plantations are conducted on scientific principles; and the rubber collected is treated by machinery which converts it into flat pancakes named "biscuits," or thin strips called *crêpe*.

The reader must be cautioned against confusing rubber (caoutchouc) with gutta-percha. The latter is a resinous sap extracted from a tree in much the same way as rubber latex. It resembles rubber in its resistance to water and the passage of an electric current. These qualities make it valuable for coating the wires of electric cables; but as it cannot be vulcanized, softens when warmed, and becomes brittle at low temperatures, it is not capable of being put to so many uses.

At the Silvertown Works on the Thames, near London, rubber is converted into articles of divers kinds, ranging from a motor-car tyre to an umbrella ring.

The Para rubber, when it arrives at the factory, contains from 15 to 20 per cent. of dirt and other

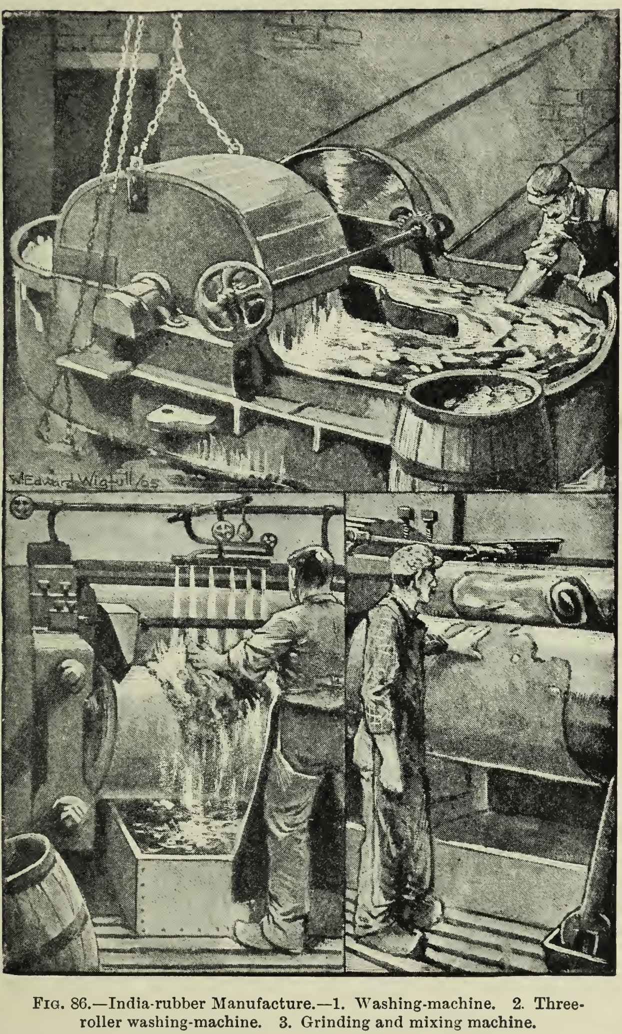


FIG. 86.—India-rubber Manufacture.—1. Washing-machine. 2. Three-roller washing-machine. 3. Grinding and mixing machine.

foreign matter, sometimes including large stones inserted by the wily native to help to "make weight." It has therefore to be cleansed at the outset. Lumps of raw rubber are thrown into a washing-machine with great toothed rollers, which tear and rend and mash the stuff and fling out all impurities. The purified rubber is then rolled into rough porous sheets. These have to be deprived of a large proportion of the water absorbed in the washing process. Formerly it was necessary to keep the sheets for several weeks in a heated chamber, as rubber is reluctant to part with its water; but this was so slow a business that another and much improved method of recent invention is now employed. The sheets are put in trays, and these are stacked one on the top of another in a chamber much resembling an iron safe. The chamber has double walls, between which steam can be circulated. When the interior has been filled with trays, the air-tight door is closed by means of screws, and a pump set in motion to exhaust all the air. Now, the temperature at which water boils depends on the air pressure, and if the latter be greatly reduced, the boiling-point sinks to a very low figure. The steam jacket, by raising the temperature of the chamber to, say, 200° F., therefore

has a much more marked effect on the moist contents than would be the case had the air not been partly extracted. The water in the rubber turns rapidly into steam without damaging the rubber, and passes out by the suction pipe, the cold surfaces of which condense it immediately. Peeping in through a little glass window into the electrically-lit interior of the pipe, we see the condensed water trickling from a nozzle.

This invention has reduced the drying period from several weeks to a couple of hours, and affords a good instance of the help given by science to the manufacturer.

The dried rubber is soft and spongy and plastic. If you take two pieces and press them hard together they will unite like dough. For most purposes it has now to be mixed with sulphur, and, if intended for the manufacture of comparatively cheap articles, with pigments and other substances which increase the bulk. The mixing is done in large mills until all the elements have been worked into a thick, clinging mass. This is passed through hot rollers and flattened out into sheets of any required thickness or pressed into moulds. But the substance has not yet lost its plastic nature. It is extensible, but not elastic; when

stretched it does not return to its original shape, but has a permanent "set." To make it elastic and fit for withstanding wear it must be vulcanized—that is, the rubber must be made to *combine chemically* with the sulphur that has been mixed with it. There are several methods of vulcanization, that most commonly used being to squeeze and heat the substance simultaneously. This robs it of its plastic character—two vulcanized bodies cannot be kneaded together cold—but renders it tougher and more able to resist considerable changes of temperature, and regain its shape after compression or extension. For making the best vulcanized rubber ten parts of sulphur are added to ninety parts of rubber. By increasing the proportion of sulphur to about 40 per cent., and heating to a higher temperature, the hard, brittle substance known as "vulcanite" or "ebonite" is obtained. This takes a high polish, and is very valuable to the electrician as an insulating material, and to the chemist and maker of photographic dishes.

After this preliminary survey of the mode of preparation, we may proceed to the workshops. In the first one entered square tiles for the flooring of banks and ships' decks are being cut from thick sheets, and shaped and vulcanized between the two steam-heated

mould-plates of a powerful press. Close by, the pads for cycle pedals are being similarly treated. Another shop is devoted to the insulation of copper wires with unvulcanized rubber. Four separate wires pass abreast between two rollers, in which there are semicircular grooves having a rather larger diameter than the wire. The attendant feeds in strips of soft rubber above and below the wires. These strips are dragged into the rollers, which divide them into shreds longitudinally, and squeeze them round the wires to form an insulating cover.

Cables are rubber-coated in a different manner, by being drawn slowly through a machine from the front of which projects a revolving arm carrying a reel of rubber tape. The last is quickly wound off on to the cable, and the edges are consolidated by pressure and heat in another apparatus. The rubber is in turn coated with cotton, "braided" on by a number of bobbins revolving among themselves so that the threads constantly cross and interlace. Should any strand break, the machine stops automatically. A cable destined for underground work is protected in a leaden sheath by being dragged through a die in a hydraulic press. In the top of the press is a cylinder filled with lead, which the piston, exerting

some five tons pressure to the square inch, drives out as a tube between the cable and the walls of the die. Marine cables have the conducting core protected successively by (*a*) the insulating material, usually gutta-percha; (*b*) a coating of hemp; (*c*) galvanized steel wires; (*d*) an external hemp wrapping. For shallow water near land (*c*) and (*d*) are sometimes repeated.

One of the most interesting things to be seen in this large factory is the making of tennis balls. Each ball consists of three oval "gores," stuck together by the edges. Boys, armed with sharp knives and bevelled cutting shapes, rip the gores out of white sheet rubber. The gores are accurately weighed and sorted according to their weight by automatic machinery, which drops them out into little bins. It is important that all "match" balls should be of a standard weight; so an unduly light gore is paired off with one that is a trifle too heavy, to give a correct average.

Girls stick one edge each of two gores to the two edges of the third, and cement to the inside a thick circular button of solid rubber. After examination with a tiny electric lamp a little water is dropped into the ball, and the two free edges are stuck

together. Then the ball is placed in a spherical mould, and heated until the water inside it turns to steam and presses the rubber tightly against the mould, vulcanizing the rubber, sealing the joints, and giving the whole a globular form. But the ball has as yet no bounce, and must be inflated. At a long table are sitting a row of girls, each provided with a tube leading from a reservoir of compressed air, and ending in a nozzle almost as fine as a needle's point. A girl takes the ball, smears the nozzle over with a little rubber solution, and pushes it through the ball at a mark indicating the position of the button inside. A metal plate with a circular opening in it is held round the equator of the ball. On a valve being opened, air rushes into the ball, which is allowed to expand until it exactly fills the hole in the plate. Then the air is shut off and the nozzle extracted. The smear of rubber solution seals the puncture, but to make things doubly sure a little more solution is applied to the point of entry.

It only remains to test the ball's bouncing powers, and if it comes up to the standard, to pack it.

So many kinds of articles are made in the factory that we cannot notice more than a few of them. Here is a girl making umbrella rings. She takes a

short length of thin rubber tubing, slips it over a steel rod, and coats the outside with rubber solution. Then, beginning at one end, she rolls the tube up into a ring. It is a very simple and quick operation.

We may linger a moment, too, at a machine which converts short bars of vulcanite into stoppers for mineral water and beer bottles. A bar is dropped into a heated mould made in two halves, which are easily separated. Down comes a plunger and squeezes the softened vulcanite into the recesses of the mould. A second later the mould opens, and out falls the stopper, flat at the upper end, on which is stamped the name of the firm that will use it, and shaped below like a screw to engage with the corresponding threads in the bottle's neck. The rough projections made by the mould joints have to be cut off with a knife, and a rubber ring slipped into a groove, before the stopper is considered complete.

As these articles are made by piecework, they are counted by a girl, who pours a quantity on to a tray having a certain number of holes in it. The stoppers are swept hither and thither by hand until every hole is full, the surplus is removed, and the trayful is registered and emptied.

Chapter XIII.

ROUND A BISCUIT FACTORY.

Biscuits—The greatest makers—Biscuits and Bibles—The Reading factory—A fine model—The flour store—Mixing ingredients—Rolling—Cutting—Baking—Sorting—Broken biscuits—Packing—Soldering the tins for export—Commerce and geography—Cracknels—Cakes—An artist in sugar—Cleaning tins—Precautions against fire.

BISCUITS! What a number of pleasant associations group themselves round this word! Biscuits—welcomed in the nursery, prized at school, and much respected by those who have long passed the stage when sweets and pastries are among the most desirable things of life. Yes, the biscuit, the "twice-cooked" comestible, suits all ages, and seems to be gaining in popularity every year, to judge by the enormous quantities of it that are consumed.

Now, if you were asked to name some one who makes biscuits, it is ten to one that you would reply without hesitation, "Huntley and Palmers." And this because, though there are many makers, the great

Reading biscuit firm outmakes all others. Wherever you go—in Great Britain, in the Colonies, on the Continent, or in other civilized regions—you will see the well-known label of Huntley and Palmers. Even in the recesses of Asia and Africa the Reading biscuit is known, and the tin which holds or held it is highly valued. An amusing proof of this is given in an announcement made by the British and Foreign Bible Society in 1896, to the effect that Bibles sent out to Uganda had to be of a peculiar shape—about 4 inches broad by 3 inches thick—in order that they might fit into one of Huntley and Palmers' 2-lb. biscuit tins, "which the Baganda use to preserve their books from destruction by vermin." So you have the picture of these folk going to church on Sunday, each carrying under his or her arm a tin as the local counterpart of the village dame's book-bag.

The Reading biscuit factory is the largest of its kind in the world. It covers twenty-four acres, and employs between six and seven thousand people. The sight of the workers pouring out of the gates at dinner-time is something to remember. Startling indeed has been the development of the enterprise which the late Mr. George Palmer set on foot in 1841, when he began making biscuits for the cus-

tomers who did business with a confectioner's shop owned by him and Mr. Thomas Huntley. In that year a few trays sufficed to transport the daily output; but now continuous trains are daily dispatched from the works, loaded with the biscuits made during the previous twenty-four hours.

A very good idea of the immense extent of the factory is gained from a splendid model standing in the entrance offices, under a glass case measuring about 7 by 6 feet. Every external detail of the premises is represented—the great blocks of buildings, the tall chimneys, the piles of timber out of which packing-cases are made, huge stacks of coal, railway sidings, wagons, and so on. This model, by-the-bye, was sent to the Paris Exhibition of 1900, and attracted a great deal of attention.

Owing to the position of the various stores and departments, the visitor does not make the tour of them in what may be called a logical order. But for the sake of clearness I will present the process of manufacture to you in due sequence, beginning at the beginning and ending at the end.

First, then, we enter a large store filled with a thousand sacks of flour. This is but one of several similar storerooms, and the quantity may indeed

seem prodigious. But remember the flour is used up at the rate of several hundred sacks a day, so it is necessary to keep in stock plenty of the material which forms the bulk of every biscuit. Of course, huge quantities of other ingredients are used, and we should be astonished by a sight of the store-keeper's books. Just to give you some idea of the scale on which the catering is done, I may mention that the butter and milk used *daily* represent the yield of more than nineteen thousand cows, and the eggs that of some one hundred and fifty thousand hens!

The various materials meet in the measuring-room, where they are apportioned out and blended in many ways, suitably for the four hundred or more varieties of biscuits that are made in the factory. From the measuring they descend to the mixing department on trucks or through shoots, the latter having their lower ends immediately over the mixing-machines. These are of several kinds, one type being a cylinder with arms revolving inside; another, a circular trough which carries the contents round and round under a big roller. In an astonishingly short time the dough for "Ginger Nuts," "Petit Beurre," "Marie," "Lunch," etc., is thoroughly kneaded. The attendant digs it

out into trucks and sends it away to a mechanical roller, through which it passes, and is flattened out this way and that into a blanket about half an inch thick. The dough of Petit Beurre is very smooth, and when stretched out thin suggests white rubber sheeting. It would puzzle a cook to produce such a compound.

Presently the sheets of dough are transferred to other rollers, by which their thickness is reduced to somewhat less than an eighth of an inch, and travel forward on a canvas belt to a machine which stamps out numerous discs at each stroke, and impresses the name and pattern on their upper side. The discs continue their journey horizontally, but the "scissel"—to borrow a term from our chapter on the Mint—is carried upwards in a slanting direction, over a roller, and deposited in a trough, to be kneaded up and rolled out again.

The shapes—we cannot very well call them biscuits yet—slide from the end of the belt on to trays which are moving at the same pace on a rather lower level, and are transferred to another belt—this time made of iron bars—on which they progress very slowly through a long tunnel-like oven. The ends of this are open, and by stooping down you can see men at

the other end removing the trays of what, by the time they reach the exit, are real biscuits, "done to a turn."

Each tray is dexterously emptied into a shallow tray, and when a sufficient number of these have accumulated they are put on a truck and wheeled off

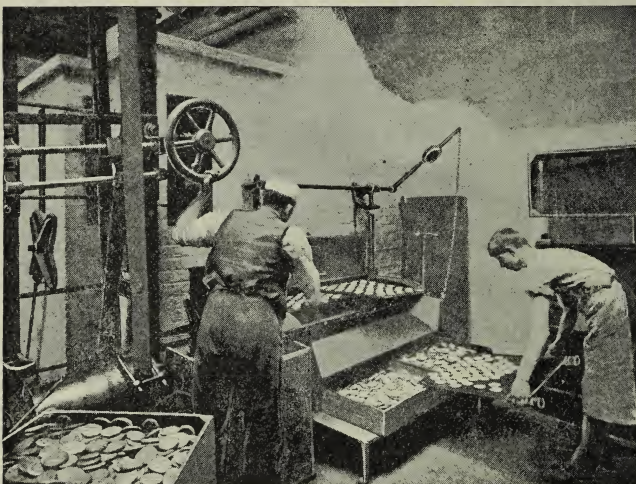


Fig. 87.—Removing Biscuits from Oven.

to the sorting department. A regular network of miniature railways traverses the factory in all directions. The rails are about 18 inches apart, and the total length of the "system" is some 12 miles. The locomotives, it should be stated, are human beings, as the propulsion of a truck is a very easy matter.

The sorting-rooms are many in number. As fast as the biscuits arrive they are lifted on to big tables and carefully examined. Every biscuit that is badly shaped or the least bit over- or under-baked is ruthlessly separated from its fellows and handed over to a staff of boys, who spend their time in breaking them up with suitable tools, so that they may not get into good company. One feels almost sorry for the biscuits, since to the outsider most of them look perfect. But here everything must *be* perfect, and it is by maintaining such a high standard that the fame of "Huntley and Palmers" has been established.

What becomes of all these broken biscuits? Every Saturday at noon each of the employees receives as a gift a bag of the better-class "rejections." Some three tons weight is distributed in this manner. The cheaper varieties of broken biscuits are sold at a very low rate in suitable markets.

The sorted biscuits go to the packers, who arrange them neatly in tins, putting a sheet of paper between every two layers. For export, some kinds are packed in tin-lined barrels. But whatever be the receptacle, if the contents are destined for the Colonies or foreign countries over the seas, the cover is soldered down to keep air and damp out, and in the case of tin boxes a

second lid is placed over that, for use when the cover has been torn off.

"Rich Mixed" biscuits deserve a word all to themselves. The various sorts included in the mixture are poured into a series of stalls open at one side. An

FIG. 88.—Packing Biscuits.

attendant wheels a large bucket quickly past the stalls, scooping off the proper quantity of each kind as he goes. The bucket is shaken and emptied into the large tins; but the small tins have to be packed carefully, each variety having its appointed place in the "geography" of the tinful.

The tins being packed, if for "export," their safety covers are soldered on by skilled workmen using a copper bit kept at a certain heat by an internal gas flame. The workman takes a flat rectangle of tinned iron, lays it on the tin—which has its upper edges turned over—dabs on some flux, and with a few sweeps of his bit runs solder along all the four edges of the plate. The tin is then examined, and if found air-tight, is handed over to the people who put the paper wrappers on. This operation takes but a very few moments, one person applying the main wrapper for the top and sides, another the slip on the bottom.

Then the boxes are put into cupboards through which a blast of hot air is driven by fans, and soon the labels are dry. To protect it from dirt, each box is enclosed in a covering of semi-transparent paper.

And now we reach the last factory stage—namely, the arranging of the tins in large wooden cases, which are nailed up and addressed. A large number of stencil plates, kept handy on nails projecting from the rafters overhead, help to expedite this process. The names on the plates range from one end of the world to the other: we see Jerusalem, Jaffa, Bulawayo, Wady Halfa, Hong-Kong, Monte Video—to mention but a few of several scores. On one box is an array

of curious Chinese characters, which announce to the Celestial that certain "barbarians"—to wit, Messrs. Huntley and Palmers—are the makers of the contents.

When the final touch has been given to it, the case

Fig. 89.—Packing Tins of Biscuits in Cases.

is slid down a well-arranged shoot to the dispatching department, where a row of trucks are being loaded for the special trains. To-morrow the millions of biscuits among which we have passed will be speeding north, east, south, and west. Could we but

follow them with fancy's eye, into what varied scenes should we be taken!

Besides the "export" trade, which has been emphasized in the above paragraphs, there is, of course, a huge "home" trade, and to cope with this a number of other departments, all run on the same lines as those here briefly described, are kept busy from the beginning to the end of each week.

As no fewer than four hundred kinds of biscuits are manufactured on the premises, there must be great variation in the methods of preparing a biscuit. Perhaps the most interesting is the "Cracknel," that always reminds me by its behaviour of the proverbial Dead Sea apple, which, though of a solid appearance, turns to dust in the mouth. Not that I have ever sampled an apple of the sort mentioned, nor that I would suggest that the "Cracknel" proves a bitter morsel. But if you have ever taken part in one of those contests in which you have to devour a certain number of cracknels more quickly than your antagonist swallows a glassful of water by spoonfuls, you will understand what I mean.

A "Cracknel" passes through two processes. First, it is thrown into a great cauldron and boiled until it rises to the surface and bobs about. Then the attend-

ant lands it with a net, and sends it to the ovens to be baked in the ordinary manner. Cunning housekeepers sometimes treat a fowl of rather advanced years similarly: they boil it first to make it tender, and roast it afterwards to give it a nice brown colour.

Now, I had almost forgotten to mention that *cakes* form a very important item of the output of this factory. Their names, too, are household words. In one room stands a monster wedding cake about five feet high, topped with pinnacles, columns, flowers, traceries, and festoons, all made out of pure sugar by a man who is a real artist in this particular form of decoration. His tools are very simple—a few bags with tapering nozzles, from which the semi-liquid sugar oozes in obedience to gentle pressure. A circular wooden table is the "canvas" on which he sketches designs for the edification of visitors. This way a stroke, that way a stroke; a blob, then some thin streams of sugar; more strokes, a twist or two, and there lies before you a bunch of camellias—leaves, stalks, delicately-petalled flowers, all complete. The table is turned round a little, and a lyre is drawn with a rapidity which would put the "lightning artist" of an exhibition on his mettle. Then a

robin sitting on a twig, and a swan swimming in a stream. It is really quite a wonderful little side-show.

A biscuit tin that goes abroad remains abroad. A large proportion of those that go to shops and stores in the United Kingdom are returned to Reading to be refilled. Before they do duty again they have to be scoured, boiled till they shed their paper wrappings and every crumb has been extracted, and finally they are baked. The microbe doesn't have the chance of being included with a pound of biscuits.

If fire once got hold of the cases and other dry materials what a blaze there would be! However, you need not be anxious, for the annals of the firm do not record any such disaster in the past, and there is little likelihood of one happening in the future. A large number of the employees have been carefully drilled in fire-brigade practice. Telephones connect the factory with the dwelling of every fireman, and in a few seconds an alarm would summon each man to his post if a fire broke out at night. In addition to human beings, mechanical devices keep a constant watch and ward. Under many of the ceilings run water-pipes, having in them, at short intervals, vents closed by fusible plugs which melt at a low tempera-

ture. Even if the Fire King stole a march on the employees, he could not hoodwink the automatic sprinkler, and soon he would let loose upon himself torrents of water, which would keep him at bay till the firemen and their hoses appeared on the scene.

Chapter XIV.

THE SMELTING OF IRON.

King Iron—The value of a nail—Iron and warfare—The world's annual output—A marvellous growth—Early history of iron smelting in England—Dud Dudley—Abraham Darby and his cooking-pots—The composition and distribution of iron ores—Bilbao—The Lake Superior deposits—Steam-shovels at work—A blast furnace—The hot blast—Neilson's great invention—Heating the blast—Power from furnace gases—A blast furnace in action—Big blast furnaces—What takes place in the furnace—A little chemistry—Iron and steel—Properties of iron and steel.

IRON is one of the foundations on which civilization has been built up. Were iron suddenly removed from the earth the whole fabric of human society would come down with a crash, and we should be more helpless in many ways than the cave man who managed to keep himself alive by the aid of his rude stone implements of the chase. To what a pitch has risen the employment of iron, and yet more that of steel! Steel transports us swiftly from place to place over a bed of steel. The steel girder has replaced the wooden bridge truss. From steel are

fashioned the myriad machines which shape the materials that make life comfortable for us. Show me something which has been manufactured without the utilization of steel. The very "wooden walls" that once guarded our shores have given way to floating forts of steel, armed with mighty steel weapons of destruction.

Captain Cook wrote, one hundred and thirty years ago, that "an Otaheitan chief who had got two nails in his possession received no small emolument by letting out the use of them to his neighbours for the purpose of boring holes when their own methods failed or were thought too tedious." So among all savage races iron, the most useful of metals, is a precious possession; and it is noticeable that, though nations have become skilled in the arts of peace and war without having any knowledge of iron, they have invariably been worsted when attacked by races well acquainted with its uses. Also, that the white man has, with few exceptions, asserted his superiority in the face of great odds in all parts of the world, largely on account of his scientific application of the metal.

To-day iron is a great force in peace as well as in war. It has been said that that nation will lead the

way which can produce a ton of steel at the lowest price. The greatness of England, America, and Germany is due largely to their skill in the production and working of iron and steel, which form between them the greatest industry of the world. Last year's total output of pig-iron is estimated at 60,000,000 tons, to which America contributed 25,000,000, Germany 12,000,000, and Great Britain 10,000,000 tons respectively. No business is conducted on so huge a scale. None demands such strenuous labour, the employment of such huge and powerful machinery, and the investment of so much capital. None has provoked man's ingenuity more strikingly or rewarded the inventor in more princely fashion. With iron are bound up some of the most colossal fortunes ever compiled. Fifty years ago a small forge was started at Girty's Run, Pennsylvania. "It stood on the edge of a straggling village, and a muddy road ran past it along the river bank. Judged by modern standards, it was an insignificant affair, with a little engine and a wooden trip-hammer—that first cumbrous mechanical substitute for the sledge-hammer."* From that humble workshop grew and spread the huge Carnegie Iron Company, which in 1901 was sold by the then owners

* "The Carnegie Millions and the Men who made them," page 1.

FIG. 90.—Blast Furnaces at Carron.—The furnaces stand in front; behind are the stoves (with domed tops). The material for charging the furnaces is lifted on to the gallery connecting their summits.

to the United States Steel Corporation for nearly 500,000,000 dollars.

The history of iron and steel manufacture begins at a much later date than that of other metals, for the very sufficient reason that, though no metal is more widely diffused than iron, it never occurs in a native or pure state, except as the meteorites which occasionally startle us by their glowing descent from the heavens. As Dr. Smiles has it: "To recognize its ores, and then to separate the metal from its matrix, demands the exercise of no small amount of observation and invention. Persons unacquainted with minerals would be unable to discover the slightest affinity between the rough ironstone as brought up from the mine and the iron and steel of commerce. To unpractised eyes it would seem to possess no properties in common, and it is only after subjecting the stone to severe processes of manufacture that usable metal can be obtained from it." It has been suggested that the metal was discovered by the accidental roasting of some ore in a fire. We cannot doubt that when once the metal had been found, its peculiar qualities caused men to search for it diligently. At the time of Cæsar's invasion of Britain the inhabitants had already possessed themselves of it, though prob-

ably only in such small quantities as could be produced by the rudest of wind-fanned hearths scooped in the side of a hill. Twelve hundred years had to pass before the wave of knowledge which originated in the East reached England, and started the industry which was presently to attain such huge proportions in this country. Then furnaces were erected in Sussex, Gloucestershire, and South Wales, and fed

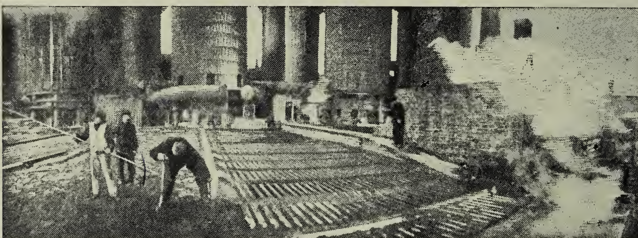


FIG. 91.—Tapping a Blast Furnace. In the foreground are seen the moulds into which the liquid iron is guided from the main trench.

with wood, a proceeding that presently so seriously diminished the great forests which once covered the land, that in Elizabeth's reign an Act was passed pronouncing it illegal to convert wood into charcoal for the making of iron within fourteen miles of the Thames, and thereby checking the ironmasters of Sussex, then the "Black Country" of England. Twenty years later Dud Dudley, son of Lord Edward Dudley of Dudley Castle in Worcestershire, took out a patent

for the smelting of iron with coal; and used it to such good effect that conservative smelters, jealous of his success, spread calumnious reports about the bad quality of his iron, and after unavailing appeals to King James to forbid the innovation, proceeded to a campaign of personal persecution which eventually drove poor Dud from the field. His invention had paid the usual penalty exacted from one that arrives before its time.

In consequence of this opposition to the use of coal, the English iron industry declined so rapidly that by the middle of the eighteenth century the annual output was not more than 18,000 tons, and at last ironmasters were driven by sheer necessity to turn to the rejected fuel. Abraham Darby of Coalbrookdale, who was the first to avail himself of Dudley's invention on a large scale, made a fortune by casting iron pots for domestic purposes. Others soon followed his example, and the fortunate occurrence of some varieties of iron ore in close proximity to the coal needed to smelt them, and to the limestone required for a furnace flux, caused the industry to go forward by leaps and bounds. The technical improvements introduced, and the new processes of producing iron and steel invented by Reynolds, Huntsman, Cort,

Bessemer, Mushet, Roebuck, Neilson, Gilchrist, Thomas, Siemens,* and other Britons, have made the iron industry what it is at the present day.

COMPOSITION AND DISTRIBUTION OF IRON ORES.

We have already remarked that iron is very widely distributed. It is known to exist in practically every part of the world. The metal occurs in chemical combination with—(*a*) A large proportion of *sulphur*, in which case it is called *iron pyrites;* (*b*) oxygen, as *oxides* of iron, the most important of which are *magnetite*—also named magnetic iron ore or loadstone—and *hæmatite*, of various colours; (*c*) carbon and oxygen, as *carbonates* of iron, found chiefly in the Coal Measures of England and Western Pennsylvania, and till comparatively recently the main foundation of the iron trade in these countries.

Iron carbonates generally contain a large proportion of clay and sand, and other impurities.

Magnetite and hæmatite, taken as a whole, are the ores richest in iron, averaging from 50 to 55 per cent. The best Swedish ore rises as high as 72 per cent. of iron.

* German by birth, but English by naturalization.

Carbonates average from 30 to 35 per cent., but their comparative poorness is counteracted by their occurrence in proximity to coal and limestone.

Iron pyrites is useless to the smelter on account of the large proportion of sulphur it contains.

Iron ore poorer than 25 per cent. does not pay for the cost of treatment in the blast furnace. Thomas Edison, the great inventor, seeing that vast quantities of ore would otherwise be wasted, introduced a process of crushing the ore to dust, and separating the iron-bearing particles from the rubbish by allowing the dust to fall in front of powerful magnets which deflect the iron into one hopper, while the non-metallic residue falls directly into another.

The most extensive ore deposits belong to the oxide group. Bilbao, in the Spanish province of Biscay, boasts whole mountains of hæmatite, from which some 5,000,000 tons of ore are quarried annually. Dannemora, in Sweden, has world-famous mines of the purest ore known that has been worked for centuries, and still commands top prices. Perhaps the most remarkable oxide deposit is that extending across Northern Michigan, Wisconsin, and Minnesota (of the Lake Superior region), and including the Gogebic, Vermilion, and Mesabi Hills. In the Mesabi district

the ore "lies on the slopes of the hills in immense masses with little soil above it. The steam-shovels used [to remove it] are similar to those known in Great Britain as 'steam-navvies,' but are larger and more powerful. Those of the most modern type have three separate pairs of cylinders and one boiler. They weigh 92 tons, and cost about £1,900 each. One machine has filled two hundred and thirty-three 25-ton ore wagons, or a total of 5,825 tons, in nine hours, but this is a record performance. Five tons of ore can be lifted by the machine at each stroke, and five full-weight lifts will fill a wagon. Ten men, exclusive of the train men, are required to work the machine, which consumes about 4 cwt. of coal an hour........The Mountain iron mine........is half a mile long by 1,200 feet broad, and at present 85 feet deep. It is worked in horizontal slices of 20 feet, the vertical range of the steam-shovel......A train of from ten to twelve 25-ton wagons is run alongside a steam-shovel, and is worked forward by a locomotive as fast as the wagons are filled. It is then drawn out, sorted, and made up into longer trains for transport to the docks (on Lake Superior). These trains usually consist of forty-four wagons, whether full or empty. Whilst one engine is attending a steam-shovel, another is

preparing a set of empties to replace those drawn out full. In this way the work is almost continuous."*

The ore thus extracted, at a cost of about 10d. a ton, is sent on large vessels, *viâ* the lakes, to Pittsburg, where it meets the millions of tons of coke sent to that city from Connellsville, and is smelted. It is calculated that though the Lake Superior ore beds are robbed of 15,000,000 tons per annum, the present generation will not see them exhausted, as the Mesabi Iron Mountain alone has 500,000,000 tons untouched.

THE SEPARATION OF IRON FROM ORE.

The earliest iron-workers merely piled ore and fuel together in a confined space, and allowed the wind to force the fire sufficiently to cause the iron to melt out and run to the bottom of the furnace. It was then reheated and beaten to squeeze out the impurities. At a later period bellows and a forced draught came into use; special furnaces were built of increasing dimensions; and the system was introduced of employing limestone and other materials as "fluxes," which under the influence of great heat combine with the greater part of the impurities in the ore.

In modern practice all ore passes through the *blast*

* *Cassier's Magazine.*

furnace. The iron so obtained, and known as "cast iron," is, so to speak, the raw material out of which all kinds of iron and steel are subsequently made. Therefore, before going further, we will give a brief description of an up-to-date blast furnace, such as is used in all large smelting centres.

The blast furnace (Fig. 92) in its typical form consists of a circular shaft or chamber made up of two truncated cones joined at their bases. The upper, named the "stack," is placed upright; the lower, the "hearth," is inverted. The broadest part of the furnace, where the two cones meet, is known as the "boshes." The top of the stack is closed by a conical trap C, which can be lowered to allow a charge of ore, limestone, or fuel to be shot into the furnace. Openings OO in the sides of the stack just below the trap lead off the hot gases formed within.

A large pipe P running outside the hearth sends off at intervals nozzles TT, called "tuyères," or "twyers," which penetrate the walls of the hearth and introduce the forced draught.

The hearth has one opening S, called the "cinder hole," through which to draw off the slag; and another at a lower level I, for the "tapping" from time to time of the liquid iron.

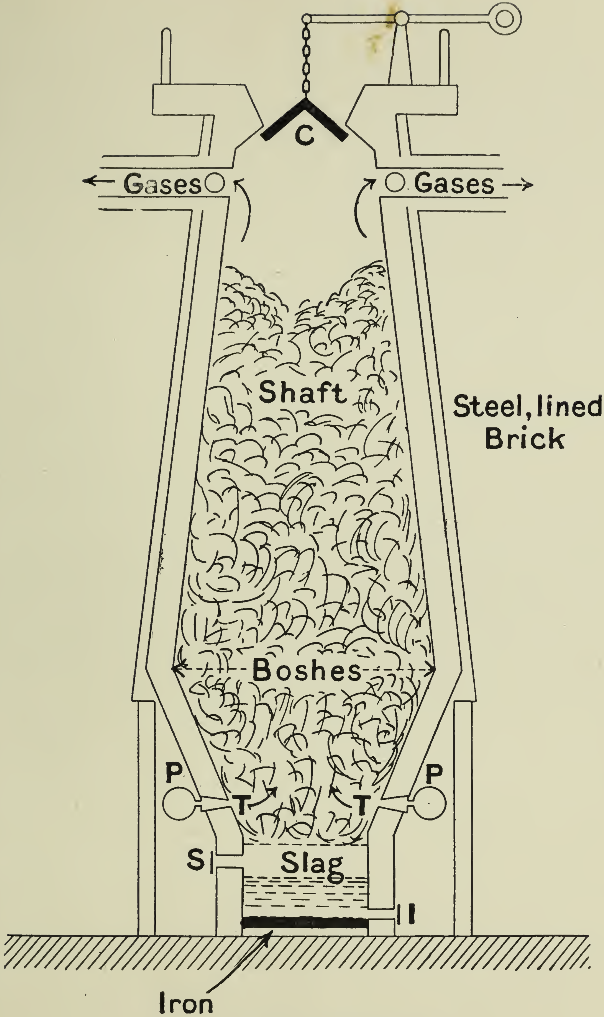


FIG. 92.—Section of Blast Furnace.

The walls of the furnace have a lining of very refractory (heat resisting) fireclay bricks, enclosed in masonry, and covered outside with a stout casing of iron plate. Massive iron pillars are usually employed to carry the weight of the shaft and its appurtenances, the hearth being supported by a solid bed of brick-work and metal. On account of the terrific heat (3,000° F.), it is necessary to cool the hearth and tuyères by means of water circulating round those parts.

HOT BLAST.

Iron smelting has been revolutionized by the introduction of the hot blast and the employment of furnace gases for heating the blast and driving the blowing machinery. The hot blast was the invention of James Beaumont Neilson, a Scottish gas engineer, who obtained a patent for it in 1828, and after much litigation and expense succeeded in establishing it, with much well-deserved profit to himself. Prior to 1828, ironmasters had endeavoured to obtain as *cold* a blast as possible, being misled by the fact that the best iron was produced in the winter; and carried their efforts so far as to paint valve-covers white, pass the air over cold water, and even cool the air pipes with ice. Neilson's reversal of the process was at

first ridiculed as the foolish imagination of a mere gas engineer; but when, after many experiments, he proved that the hot blast effected an enormous economy in fuel, opinion veered round, and his previous detractors tried to rob him of the fruits of his brilliant discovery, which, though eminently simple in its conception, soon trebled the output of the furnaces to which it was applied. As early as 1845 no less than £650,000 sterling was saved on the fuel bill of the Scottish furnaces, which in that year produced 200,000 tons of pig iron.

Neilson heated his blast by passing it through pipes exposed to the flames of special furnaces. A further, and almost equally great, saving in fuel has been effected by using the combustible gases issuing from the furnace—which were previously allowed to escape into the open air—for heating stoves through which cold air is blown to have its temperature raised on its way to the furnace.

Fig. 93 is a sectional diagram of a Cowper "regenerative" stove—a very commonly used heat-trap—and the various pipes and valves regulating its action. As shown, the valves are arranged for the heating period. Hot gases enter from the throat of the furnace through pipe A, pass up a large central

pipe C, in which they are mixed with air entering by B, and ignite. From the top of C the flames pass downwards through DD, stacks of firebrick, which are heated to redness, and the burnt gas makes its way out into the chimney F through E.

In about two hours' time the whole contents of the chamber are brought to a strong red-heat. Then the

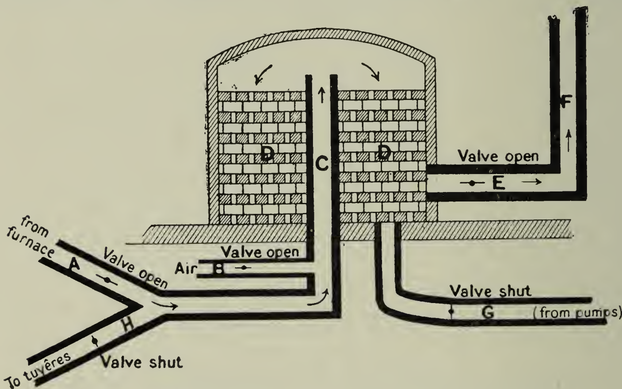


FIG. 93.—Diagrammatic section of a Stove for heating the Blast to a Smelting Furnace.

valves in A, B, and E are closed, and those in G and H opened. The cold blast is forced in by G, travels up through DD, down C, and out by H to the tuyères in the furnace hearth, attaining on the way a temperature of about 700° to 800° F. Blast is continued until the stove has cooled to a certain point, and then the valves are reversed again. In order to maintain a

constant hot blast, two, three, or four stoves, together as large as the furnace itself, are used and worked in rotation.

The hotter the blast the hotter are the gases that come off, and the hotter the stoves can be made in turn, so that there is no difficulty in obtaining a blast of 1,500° F. by "regeneration."

POWER FROM FURNACE GASES.

There is usually sufficient gas created in the furnace to heat the stoves, and also provide fuel for the blowing engines. In some cases the gas is burned under boilers to raise steam for the engines; in others it is cleansed, cooled, and used directly in gas-engines, which in some of the largest smelteries are of 1,500 horse-power each. This is the more economical method.

In Fig. 94 you see a diagrammatic representation in "plan" of a blast furnace A, two stoves B and C, a chimney F, engines D, and pump E. B is being heated by the gases; C is heating the blast.

A BLAST FURNACE IN ACTION.

After this preliminary survey of the constructional and mechanical details, we will imagine that our

blast furnace is about to be fired up, or "blown in," as the smelter calls it. The hearth is filled with wood to a certain depth, and on this coke is dropped through the "throat" trap, until it piles up to the boshes. A light is applied, and as soon as the coke becomes incandescent, a small charge of ore and limestone is added, the blast is turned on, and further

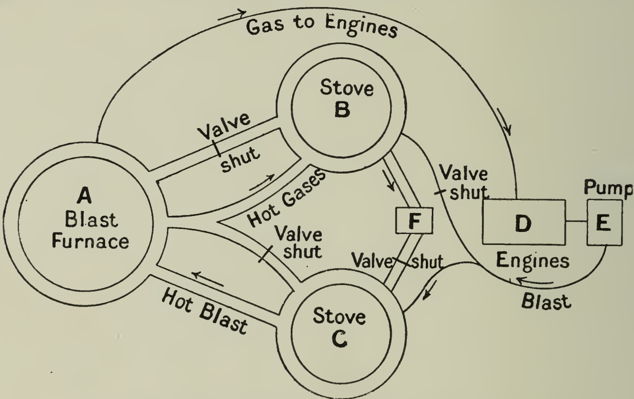


FIG. 94.—Plan of two Stoves and one Blast Furnace.

additions of ore and flux are made till the shaft is filled almost to the throat. At the end of a week or so the blast has attained its maximum working heat, and the furnace is in full swing. When once started, a furnace is kept going day and night for years together. If for any reason it becomes necessary to "blow out" a furnace, the charges are stopped and

the throat and hearth emptied by tapping off all the molten metal and liquid slag. Should its contents accidentally cool and solidify, the furnace has to be pulled down and re-erected; but such a disaster is so carefully guarded against as to be of rare occurrence.

BIG BLAST FURNACES.

The largest blast furnaces are 100 feet high and 40 feet in diameter inside. The introduction of improved methods of feeding and blowing has multiplied the productiveness of a blast furnace to a remarkable extent during the last forty years. In 1860, 50 tons per day per furnace was accounted a very satisfactory output. Each of the large Carnegie furnaces at Duquesne now makes 700 tons of pig iron every twenty-four hours, or about 200,000 tons a year, a quantity equal to one-fourth of that produced in the whole world in 1800.

WHAT TAKES PLACE IN THE FURNACE.

The furnace is filled with alternate layers of coke, ore, and limestone. There enters from below an exceedingly hot and powerful draught of air.

Now, what chemical action is needed to separate the iron from the bulk of the ore?

The *coke* is mainly carbon. The *air* is oxygen plus nitrogen. The *ore* contains iron, oxygen, silicon, sulphur, phosphorus, alumina, etc. The *limestone* is calcium oxide or lime, plus carbonic acid.

In smelting it is important to rid the ore of as much as possible of the oxygen, sulphur, phosphorus, alumina, and most of the silicon.

The carbon of the coke, uniting with the oxygen of the air, produces a gas, carbonic oxide (CO), which in turn robs the iron oxide of its oxygen, so forming metallic iron and carbonic acid gas (CO_2).

The silica, clay, etc., usually associated with the iron ore, unite with lime from the limestone, and go to form *slag*.

The iron and slag trickle down into the hearth, and the slag, being lighter, floats on the top.

In its passage through the hot fuel and ore the metal takes up from 3 to 4 per cent. of carbon and from 1 to 4 per cent. of silicon, with varying quantities of manganese and sulphur, and practically all the phosphorus occurring in the materials used.

Periodically the iron is "tapped" through a hole in the bottom of the hearth, and the silicates or slag are abstracted through another orifice at a higher level. The tapped iron may either be run into vessels

for further treatment, or into moulds to form cast-iron articles, or into a trench which branches out into smaller trenches in a bed of sand. The first branches are called "sows" (Fig. 95) and the secondary branches "pigs," from a fanciful resemblance to a sow suckling a litter of little pigs.

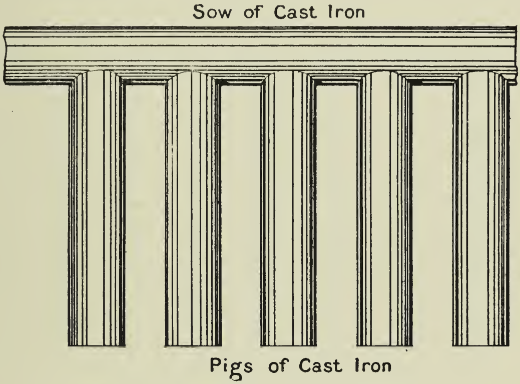


FIG. 95.—"Sow" and "Pigs" of Cast Iron.

So now we have got iron in its crudest manufactured state of *cast iron.*

If you take a piece of cast-iron plate and apply a file to it, you will find that it is very hard. If you strike it with a hammer, it will splinter, because it is very brittle.

If you examine it closely, you will see that it has a grain like lump sugar. If you are able to analyze

it, it will prove to be impure. Here is an analysis of an average sample of pig iron :—

Carbon	2·990	per cent.
Silicon	1·633	,,
Sulphur	·090	,,
Phosphorus	1·176	,,
Manganese	·396	,,
Iron	93·715	,,
Total	100·000	

The foreign matter present affects the character of the iron. The phosphorus prevents it from being forged cold. Even if the phosphorus were absent, the sulphur would render it brittle when heated to redness. Hence, though cast iron is useful for castings of a massive nature to bear heavy weights or of an ornamental character, it will not serve the many other purposes for which iron is so useful.

IRON AND STEEL.

It is possible to get rid of practically all the impurities. But pure cast iron is of little use, being too sugar-like in its texture. By a process called "puddling," followed by rolling, pure iron is produced of a fibrous, wood-like character. It is very malleable (that is, easily worked by beating) when heated, and tough; but it cannot be hardened by tempering, so as to resist wear on the surface.

Fortunately for mankind, iron combined with a *little carbon* forms a substance called *steel*, infinitely more useful than cast or malleable iron, because it combines the properties of both. It can be cast and forged afterwards into any desired shape, and subsequently be tempered to extreme hardness. Steel is also far stronger than iron. A rod of the highest quality one inch square will stand a stretching strain of 150 tons, as compared with the 20 to 30 tons' pull withstood by a cast-iron bar of the same section.

Steel therefore differs from cast iron in that it contains *less* carbon and little impurity; from malleable iron in that it contains *some* carbon. By means of a simple table the relations of iron and steel will be made clear.

Metal.	Proportion of Carbon.	Properties.
Cast iron..........	3 per cent. and upwards.	Brittle, unworkable, useful for casting.
"High" steel....	1 to 1·5 per cent.	Very tough. Takes a high temper.
"Medium" steel	·3 to ·7 per cent.	Less tough, but more malleable.
"Low" steel....	·3 and less.	Very malleable; can be slightly tempered.
Malleable iron...	The merest trace.	Most malleable; cannot be tempered; difficult to melt.

We may also notice that the "higher" in carbon steel is, the more permanently can it be *magnetized*. Malleable iron is only capable of temporary magnetization, a property which renders it extremely valuable for electrical purposes.

The problems that inventors have had to solve with regard to the iron and steel industry may be summarized thus:—

(*a*) To produce raw, cast, or pig iron in large quantities and economically; (*b*) to convert raw iron into malleable or *bar* iron; (*c*) to convert raw iron into steel cheaply.

Problem *a* has been the subject of this chapter. In the following chapters we shall study *b* and *c*.

Chapter XV.

THE MANUFACTURE OF WROUGHT IRON.

Puddling—A puddling furnace—Fettling the hearth—Melting the pig iron—Balling the iron—Extracting the iron balls—A teetotal story—Hammering the balls—Cutting and rolling—Mechanical puddlers—Rolling-mills—Rolling iron rods—Rolling tapered bars.

PIG iron, as we saw in the last chapter, contains carbon, silicon, phosphorus, sulphur, and other impurities. By a process named "puddling" these may be almost entirely removed, and an iron obtained which can be forged even without heating, is very easily welded at a red-heat, is tenacious and not liable to crack, and, generally, is very useful for the manufacture of articles with which the ordinary blacksmith has to do—such as horse-shoes, gate hinges and hasps, rails, tyres, hoops, bolts, ties, etc.

Pure wrought iron is also the foundation of the best steels, as we shall see presently.

Puddling is performed in a furnace of the type shown sectionally in Fig. 96, which was introduced

in 1784 by Henry Cort, and is known as a "reverberatory" furnace. It consists of two main parts, the furnace A, and the hearth B, separated by a low wall or fire-bridge *a*, and enclosed by thick walls and roof of firebrick. At the farther end of the hearth is a flue-bridge *b*, not quite so high as the fire-bridge, so that if there is any overflow from the hearth it shall travel down the sloping

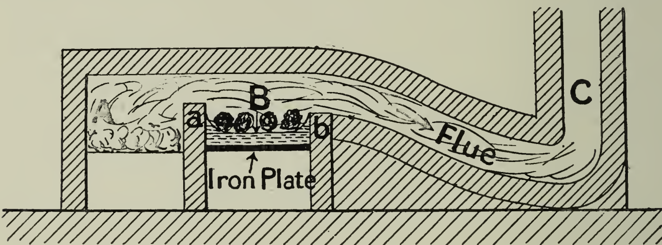


FIG. 96.—Section of Puddling Furnace.

flue to the base of the chimney C, where it is caught for extraction. A thick iron plate forms the floor of the hearth. This and the sides are covered with a "fettling" (protection) of a highly heat-resisting substance, fitly named "bulldog" by the puddlers on account of its endurance.

There is a charging door at one side of the hearth, made of fireclay slabs set in a cast-iron frame, and suspended by a chain from a lever carrying a counter-

balancing weight at the other end, so that the door may be raised and lowered easily. The lower edge of the door has in it a small arched opening, called the "stopper-hole," for the puddler to work his bars through.

When the hearth has been well "fettled" and brought to a high temperature, a charge of pig-iron and wrought-iron scrap is introduced, and the door is closed and rendered air-tight with fireclay. The furnace flames, passing over the fire-bridge, are beaten down (hence the term reverberatory) by the roof on to the charge as they pass to the flue. In about fifteen minutes the metal begins to soften, and the puddler then inserts his iron "rabble"—a long bar flattened at the end—through the stopper-hole, and moves the lumps of "pig" towards the middle of the hearth.

As the metal melts, the oxygen of the air entering with the flames combines with the iron to form ferrous oxide, and with the silicon, which combines with the ferrous oxide as slag. The carbon of the pig iron also combines with oxygen, and comes off in carbon monoxide (CO) gas, causing the surface of the now fluid charge to boil vigorously. Now is the time for the puddler and his rabble. "He searches or

sweeps every portion of the bed by moving the point of the tool in curved lines from the centre outwards towards the bridges on either side, commencing at the front. The sides are reached by a kind of scooping action, the rabbles being worked against the door frames as a fulcrum. The tool must be changed every five or ten minutes, as it would soften and adhere to the iron if left too long in the furnace. When taken out it is cooled by plunging into a cistern, or "water bosh," which detaches the adherent cinder; the point is afterwards dressed up into shape by forging with a light hammer. Usually four tools are required to be used in the boiling of one charge." *

The boiling becomes less violent as the carbon diminishes, and the bath begins to stiffen. The presence of carbon and silicon renders pig iron fusible at a lower temperature than pure iron. Now that the carbon has passed off in a gas, and the silicon combined with oxygen and some iron to form an independent slag, the bulk of the iron "comes to nature" in bright points, which rapidly coalesce and form sponge-like masses projecting from the molten slag. The phosphorus of the pig separates and

* "Metallurgy of Iron" (Bauerman), page 324.

combines with the slag, and the sulphur combines with oxygen and goes off as a gas. It therefore only remains to separate the iron from the slag. The puddler stirs up the bath well so that it may be uniformly heated. Then comes the hardest work of all—the "balling-up" of the iron. The iron particles being as mutually adhesive as half-thawed snow—to borrow a comparison from a decidedly cooler substance—the puddler works together a little lump, and rolls it about in the bath until it has grown into a roughly spherical mass weighing from 100 lbs. to 120 lbs. This he places near the fire-bridge to keep hot while he proceeds with the others. When the whole charge—about 500 lbs.—has been thus balled, the door, which has been opened for balling, is closed, and the heat increased to melt as much slag as possible out of the balls. The door is again opened, and the balls are extracted by means of a long pair of tongs with curved jaws, dropped on to a truck, and wheeled off to a steam-hammer, which pounds them so vigorously that the slag which has adhered is squeezed out like water from a sponge.

Puddling, especially the balling part, is very hard work, probably the hardest work required in the iron industry. The heat issuing from the opened working-

door distresses a visitor even if he stands a good distance away. This I know from personal experience. So you will easily understand that a man who has to stand close up to the door, and at the same time move nearly a hundredweight of iron with a heavy tool, has a rather hard time of it. Though clad in the lightest possible garments (and in very few of them), he perspires freely at every pore, and in the intervals of puddling is obliged to replace frequently the moisture he has lost. If wise, he chooses barley-water, or some other non-alcoholic drink; if unwise, beer. A story was told me by a gentleman well acquainted with iron-makers and their ways which illustrates in a very positive fashion the relative values of the two classes of drinks to a man who has to perform such strenuous work as puddling. There was in a certain ironworks a teetotal "gang"—a father and three sons—who had to endure a considerable amount of chaff from their non-abstaining fellows. In order to show that a man who drank barley-water was "a man for a' that," they challenged any four of their mates to do as good a week's work and earn as much money as they. This challenge was promptly accepted, and both parties fell to. Now, puddling at ordinary speed

is exhausting, but puddling against time taxes human endurance to the utmost. The moral of this tale lies in the fact that at the end of the week the teetotalers were sadly weary men, but still able to use their rabbles, and the non-abstainers were—in hospital. After that barley-water met with greater respect.

But we must be getting back to the steam-hammer. It beats the spongy ball into a compact mass, and

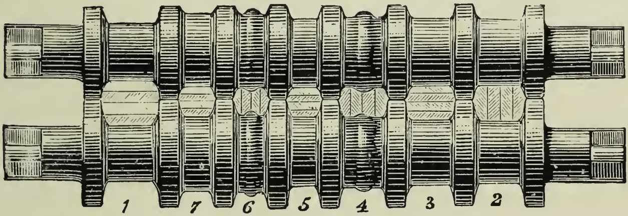


FIG. 97.—Rail-mill roughing Rolls. Observe that the rails being rolled are built up of several bars each. The numbers in the grooves refer to the order in which they are used.

elongates the mass into a short, thick bar or "bloom." This is reheated in a special furnace, and hammered again; then heated, passed through a rolling-mill, and drawn out into a long bar. The bar is cut up into short pieces, which are heated, piled on one another, and re-rolled. For the best wrought iron this process is repeated three or four times, until every trace of slag has been removed and the iron has a fibrous grain. The arrangement of the bars in the "piling"

depends largely on the purpose for which the iron is intended, so that the welded slabs may be of a convenient shape for the final rolling into T-iron, round bars, girders, axles, etc.

To reduce the cost and labour of puddling, various mechanical puddlers have been introduced, but not used to any great extent, as no machine is able to

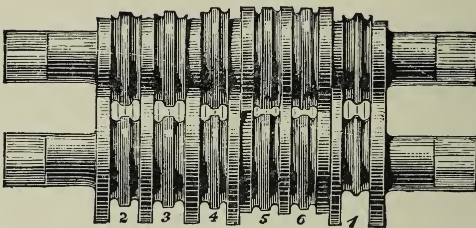


FIG. 98.—Rail finishing Rolls.

exercise the judgment that appears to be needed for the production of the best wrought iron.

ROLLING-MILLS.

In its simplest form a rolling-mill consists of two cast-iron cylinders arranged horizontally over one another, and geared together so that they shall both revolve at the same speed. For rolling thin iron plates the rolls have quite smooth surfaces; but for the production of "merchant bars" of wrought iron, grooves are sunk in their circum-

ference—the groove in either corresponding to that in the other, so that the two together may make a complete section of the shape required.

The "bloom" of iron is reduced either by bringing the rolls closer together between every two rollings,

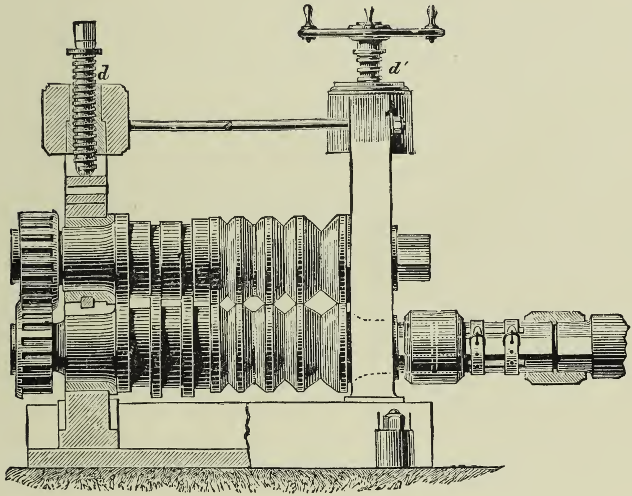


Fig. 99.—Rolling-mill for flat and square Rails.—$D\,D'$ are the screws for altering the distance between the rolls.

or by using a number of grooves of gradually diminishing size. For most kinds of small work the second method is more commonly used, and in order to save time three rollers are often placed above one another, the top and bottom being driven

by the middle, which revolves constantly in one direction. A bar is passed between the bottom and middle rolls, and returned between the middle and top rolls; and so it travels backwards and forwards until drawn out to the required length and shape. In an ironworks that I visited a party of men were reducing large bars to iron rods about $\frac{3}{8}$-inch in diameter. I was considerably impressed by the dexterity with which they seized the red-hot bar as it emerged and tossed it back into the proper groove. In the final stages the glowing rod shot out from the rolls at an astonishing pace and writhed about like a long fiery snake, and then disappeared through the rolls with a wriggle that suggested a worm "getting to ground."

When very heavy bars or large plates have to be treated, a "three-high" train of rolls is inconvenient, owing to the labour required to lift the metal, and it is usual to have only two rolls, which are reversed between every two rollings. We shall have more to say about this in a later chapter.

For rolling tapered iron and steel, such as is used in the tongues of railway switches, ingenious devices are employed to increase the distance between the rolls at a constant rate as the bar moves through

them. The rollers are set to the distance required to produce the point, and the pressure is diminished gradually, either by means of gearing or by allowing water to escape from the cylinder of a hydraulic ram pressing on one roll.

Chapter XVI.

THE MANUFACTURE OF STEEL.

Various methods of producing steel—The Bessemer process—Bessemer's account of his invention — His difficulties — David Mushet's improvement of Bessemer's principle—The Bessemer converter and its accessories—Blowing a charge of molten iron —A fine spectacle—The open-hearth process—An open hearth and its working described—Acid and basic processes of steel-making—Their respective advantages—Summary of processes in the manufacture of iron and steel—Alloy steels.

ORDINARY steel is iron combined with from ·3 to 1·5 per cent. of carbon.

It can be obtained in a variety of ways.

(1.) A bar of pure wrought iron is buried in an air-tight box filled with powdered charcoal, and heated to red-heat for several days in a furnace. The iron gradually absorbs carbon through its pores, and changes into *blister steel.* This process of conversion without melting is named "cementation." The steel produced is of but medium quality, owing to the unequal distribution of the carbon.

(2.) If, however, it be broken up and melted, out

of contact with air, in crucibles, the distribution is perfected, and *cast steel* (or *crucible steel*) of the highest grade results. The crucible method was discovered by Benjamin Huntsman, a Sheffield clockmaker, about one hundred and fifty years ago, and kept a secret by him until, one winter's night, a rival, disguised as a tramp, obtained permission to shelter in his foundry, and, while feigning sleep, watched the process which produced the best steel that could be obtained at the time.

(3.) Bar iron is melted in crucibles with charcoal and oxide of manganese.

(4.) Pig iron is melted and freed of *all* its carbon and of most other impurities by blowing air through it, and afterwards the proper amount of carbon is added. This constitutes the famous Bessemer steel process.

(5.) Pig iron is melted in an open-hearth Siemens furnace, and freed of *most* of its carbon, and of other impurities.

The different processes may be classified thus:—

(1). Starting with *bar* (pure wrought) iron, to which carbon is added either when the iron is merely heated (cementation) or when melted (crucible).

(2). Starting with *pig* iron, and either (*a*) subtract

ing *all* carbon and adding the required amount (Bessemer), or (*b*) subtracting most of the carbon (open-hearth) and adding what is necessary.

The processes of Class 2 are by far the most important commercially.

THE BESSEMER PROCESS.

In the year 1856 a Mr. Henry Bessemer read a paper before the British Association at Cheltenham, entitled "The Manufacture of Iron and Steel without Fuel." To give a quotation from this most important communication:—"I set out with the assumption that crude iron contains about 5 per cent. of carbon; that carbon cannot exist at a white-heat in the presence of oxygen without uniting therewith and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed; and lastly, that the temperature that the metal would acquire would be also dependent on the rapidity with which the oxygen and carbon were made to combine." Mr. Bessemer describes how he constructed a cylindrical vessel, lined with firebricks, and perforated at the bottom for five blast nozzles. The blast was turned on, and molten Swedish pig iron run into the vessel.

Violent boiling at once began, and from the throat of the "converter" there soon issued a bright flame, caused by the combination of carbon with the oxygen of the blast, which lasted for about twenty minutes. The sulphur was driven off, the silicon oxidized and combined with ferrous oxide to form slag. When the flame died down a tap-hole was opened, and the iron allowed to flow into the ingot moulds placed to receive it.

"Thus it will be seen that by a single process, requiring no manipulation or particular skill, and with only one workman, from three to five tons of crude iron pass into the condition of several piles of malleable iron in from thirty to thirty-five minutes, with the expenditure of about a third part of the blast now used in a finery (puddling) furnace, with an equal charge of iron, and with the consumption of no other fuel than is contained in the crude iron...... I beg to call your attention to an important fact connected with the new process which affords peculiar facilities for the manufacture of cast steel. At that stage of the process immediately following the boil the whole of the crude (pig) iron has passed into the condition of cast steel of ordinary quality. By the continuation of the process the steel so produced

gradually loses its small remaining portion of carbon, and passes successively from hard to soft steel, and from soft steel to steely iron, and eventually to very soft iron; hence at a certain period of the process *any quality of metal may be obtained*."

Bessemer's invention was ridiculed by many iron-masters. They knew that the hottest furnaces then existing could not do more than soften decarbonized iron; whereas Bessemer claimed to produce it and keep it liquid by a mere blast of *cold* air. However, a converter was set up in the Dowlais Iron Company's Works, South Wales, and five tons of iron were produced direct from blast furnace pig under Bessemer's superintendence. But when the metal came to be tested it proved to be worthless—brittle when cold ("cold short"), and rotten when red-hot ("red short")—and the poor inventor was naturally much humiliated. With characteristic pluck he spent two and a half years on experiments to discover the reason for this failure, which contrasted so unfavourably with the success of his earliest attempts. At last he determined the cause—the difference in the quality of pig iron used. The Swedish pig iron contained very little sulphur and phosphorus, that at Dowlais contained a high percentage of both. He also ascertained

that these elements cannot be removed by the blast; that their presence, and that of ferrous oxide, caused the brittleness of the completely decarbonized metal. Two things became apparent—the necessity for using pig iron containing little phosphorus and sulphur, and the advisability of adopting the process for *steel*-making only.

But even after these discoveries had been made, Bessemer found it most difficult to obtain a steel of uniform quality from the various ores that seemed suitable for his purpose. It was practically impossible to gauge the process of decarbonization during the "blow." If this proceeded too far, the metal was brittle; if it was not continued far enough, the metal was too hard and intractable. Consequently Bessemer's method, from which he and his friends expected so much, proved a comparative failure. At the critical moment David Mushet solved the problem. He had taken out a patent in 1856 for the *complete* decarbonizing of the iron, and the subsequent addition of a pig iron containing *known quantities* of carbon and manganese. The latter element renders the sulphur, phosphorus, and ferrous oxide less able to affect the quality of the metal. What Bessemer began Mushet finished; and though the first has given his

name to the complete process, Mushet deserves almost equal credit.*

THE BESSEMER CONVERTER.

To proceed to the modern development of the Bessemer system of steel-making. The "converter"

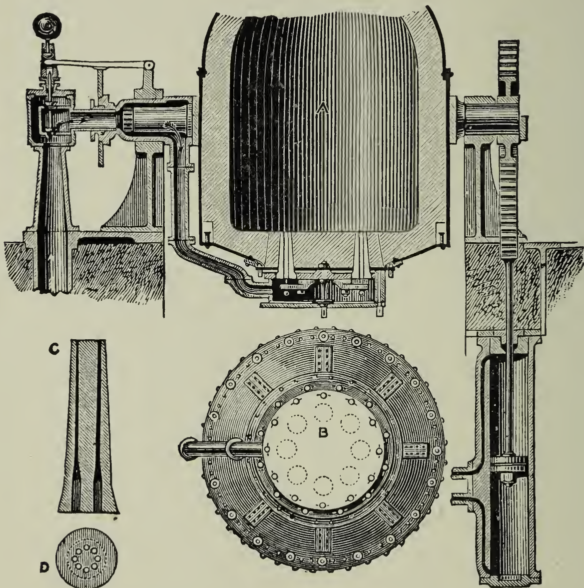


FIG. 100.—Bessemer's Steel Converter.—A, Transverse section through trunnions; B, bottom plan; C, section of tuyère brick; D, plan of ditto, showing holes.

* Another example of "honours divided" is afforded by the Bramah hydraulic press. Joseph Bramah invented the principle; Henry Maudslay made it practically useful by the invention of the self-sealing collar. See "How It Works," pages 363, 364.

most commonly used somewhat resembles in shape a short bottle with the neck bent over to one side. The outer casing is made of wrought-iron plates riveted together, the interior lining of firebrick or ganister—a nearly pure siliceous sandstone. To the bottom is attached a flat, hollow box, the tuyère case, from which seven or more firebrick tuyères, each perforated with a number of longitudinal holes, project through the lining into the interior. The converter is suspended on two trunnions projecting from the outer casing. One is solid, and carries a toothed wheel, which is operated by a vertical hydraulic ram moving a rack, so that the converter may be rotated through half a circle. The other, which is hollow, projects through an air-tight joint into the blast pipe, and has a pipe running from it to the tuyère case.

Two or more converters are arranged round the edge of a circular pit opposite openings into chimney shafts, to which their mouths are directed during the "blow." In the centre of the pit is a powerful hydraulic ram carrying on its upper end a platform of a length almost equal to the diameter of the pit. At one end of the platform is a huge ladle made of wrought iron lined with fireclay, and having in the bottom a hole closed by a plug of fireclay suspended

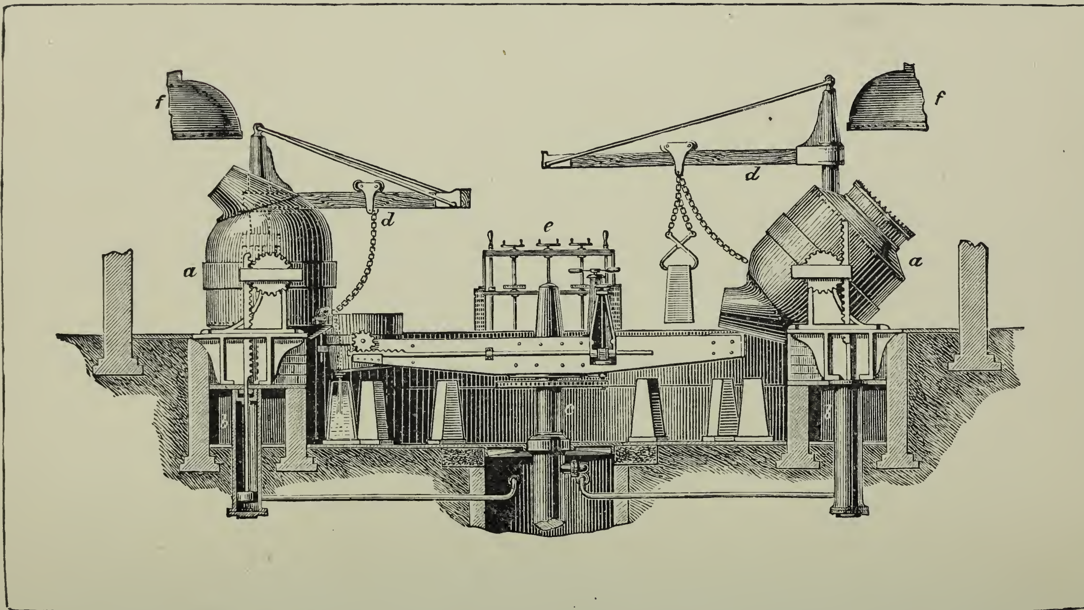


FIG. 101.—Bessemer's Steel-converting Apparatus.—*a a*, Converters; *b*, hydraulic ram for revolving converter; *c*, ram to lift platform carrying ladle; *d*, crane; *e*, gear for revolving platform; *f*, hoods to chimneys.

from an arm which can be raised by pulling on a lever on the outside of the ladle. The platform is furnished with gear for rotating it on the ram, so as to bring the ladle under the mouth of any converter.

Round the circumference of the pit are placed a number of cast-iron ingot moulds, open at both ends and tapering slightly towards the top. Other essential features of the outfit are a pump for delivering air to the converter at a pressure of from 18 lbs. to 20 lbs. to the square inch, a crane for lifting the ingot moulds out of the pit, and a cupola furnace for melting the pig (except when the iron is run direct from the blast furnace into the converter). (Fig. 101.)

THE OPERATION OF A CONVERTER.

The converter, previous to receiving a charge, is brought to a red-heat by being filled with burning coke. When the charge is ready, its hydraulic ram turns the converter upside down and empties out all the unconsumed coke, and returns it to a horizontal position. The charge of molten metal is run in through an iron gutter lined with sand. The blast is turned on, and the converter is then moved into an upright position, with its mouth pointing up the chimney.

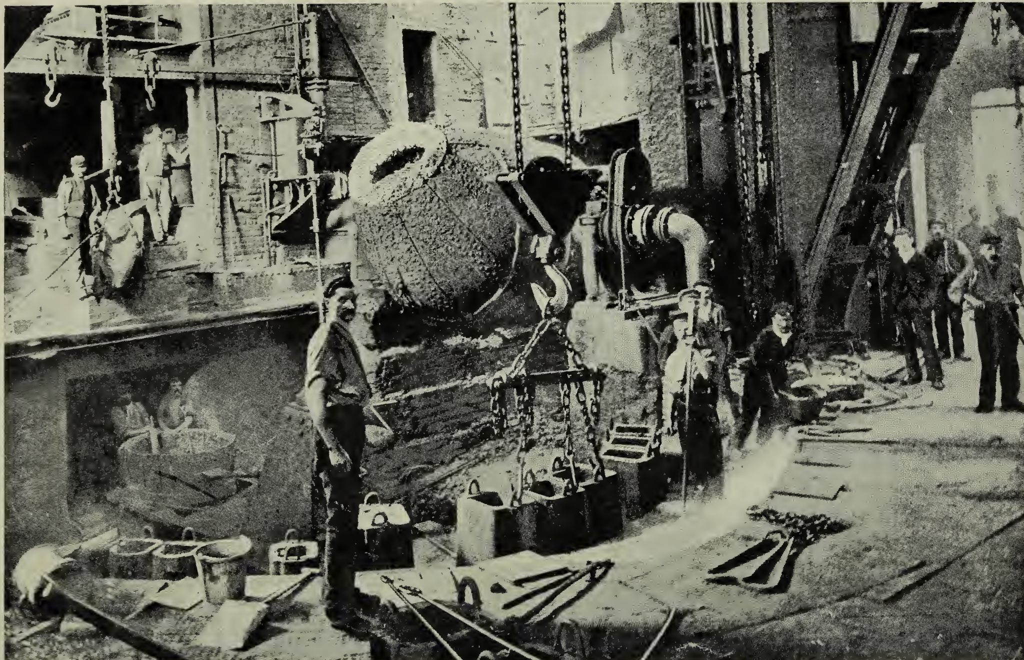


FIG. 102 —Scene in a Bessemer Steel Works.

The flame that at first issues is yellow and but slightly luminous. During the first five or six minutes the oxygen of the blast combines with the silicon and manganese present and some iron to form slag; then it begins to attack the carbon. The flame becomes brighter and brighter, till it dazzles the eyes of the onlooker. Showers of sparks and fragments of molten slag leap out, adding brilliancy to the display. Sometimes a whistle is blown, signifying "too hot," and men stationed on the platform near the mouth heave in lumps of cold iron scrap to reduce the temperature. At the end of from fourteen to fifteen minutes the sparks become fewer, and the flame changes from white to an almost invisible blue. But suddenly this changes back to an intense white, as the oxygen begins to attack the iron. The time for carbonizing and pouring has come. The converter is tipped to the horizontal position, and liquid *spiegeleisen* (iron + manganese + carbon), weighing about one-tenth of the original charge, is added. The ladle is brought round, and the opening of a hydraulic valve causes the converter to pour its 8 to 10 tons of molten metal into the ladle. The platform is then revolved so as to bring the plug-hole of the ladle over each of the moulds in turn. The plug lever is

lifted, and the white-hot liquid steel quickly fills the mould, which is then covered over with a piece of sheet iron to exclude air.

When the steel in the moulds has set sufficiently, each mould is lifted by the crane, and the ingot is extracted and placed in a "reheating pit" to allow the heat from the still molten centre to spread to the surface, which has been partly cooled by contact with the mould, and so render the ingot fit for rolling without being put in a furnace.

The average charge for a Bessemer converter is 10 tons, but as much as 20 tons is treated in the largest apparatus. The loss of weight is about 10 per cent.; the time taken from charging to pouring about twenty minutes.

THE OPEN-HEARTH PROCESS.

By this process (1) pig iron is exposed and melted on the hearth of a special type of reverberatory furnace; (2) steel scrap is added gradually, and melted, to dilute the carbon in the cast iron; (3) the heating is continued and ferric oxide added until the carbon has been nearly all burnt away, the silicon and phosphorus oxidized to slag, and the sulphur dissipated; (4) spiegel-eisen is added, and the metal

is run off. The process therefore has a resemblance, as regards its chemical action, to the Bessemer. It was invented by Heath in 1845, improved by Martin, and rendered a commercial success by Sir William Siemens, who applied the "regenerative" principle to the furnace to attain the high temperature needed for the melting of wrought iron.

A diagram of a Siemens-Martin open-hearth furnace

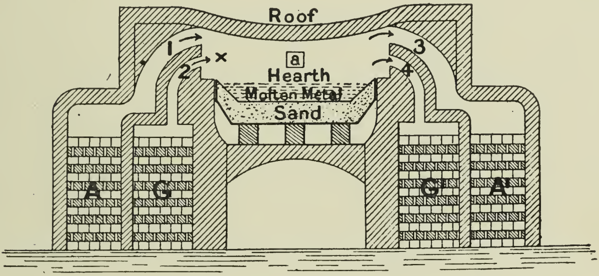


FIG. 103.—Section of an Open-hearth Regenerative Furnace.

is given in Fig. 103. The hearth has a bowl-shaped bed of a refractory substance supported by stout iron plates, under which currents of air are circulated to reduce their temperature. At each end is a regenerative stove divided into two compartments, A and A′ for air, G and G′ for gas. Each stove has valves leading to the chimney and the air and gas supplies. In the diagram air and gas are being forced through A and

G respectively. They pass up through the piles of firebricks—already hot—mix at the ends of channels 1 and 2, and combustion takes place at x. The flames are deflected by the curve of the roof on to the bath of metal, and find their way out through channels 3 and 4 and the bricks in A′ G′, which were cooled by the last current from that end. At the end of half an hour or so the valves are reversed; A′ G′ heat the air and gas to a higher temperature than did A G, and in this manner the heat in the furnace is increased at every reversal until it reaches the point required, which is ascertained by the practised eye of the furnaceman.

The charge of an open-hearth furnace ranges from 15 tons to 100 tons according to the size of the furnace, and the period required to reduce the carbon from eight to twelve hours. Samples are extracted in a long ladle from time to time through the door *a*, plunged in water to test their hardness, and broken to prove the grain; and particles are drilled out and dissolved in nitric acid to show by discoloration how much carbon is present. When the decarbonization has reached the desired limit, spiegel-eisen is added, and a tap-hole leading from the bottom of the bed is unstopped, to permit the charge to flow down a

channel into a ladle resembling in shape and construction one used for the Bessemer process, but running on rails over a trench in which the moulds are placed. As the steel flows in, men shovel manganese into the ladle down a shoot. In order to avoid faults in the ingots, it is customary to arrange the moulds in groups of four round a central funnel of fireclay connected to the bases of the moulds by fireclay pipes. Since the metal is run into the funnel fast enough to keep it full almost to the brim, a considerable pressure is maintained at the bottom, the metal rising in the moulds is kept free from gas holes, and good, solid ingots are obtained.

The *semi-continuous* open-hearth system, which is employed profitably in connection with the largest furnaces, consists of tapping off a portion of the steel at comparatively short intervals, and replacing it with pig iron. Under this system the hearth is never idle. Revolving inclined hearths, to cause the charges to "roll" under the flames, and hearths which can be tilted to empty the charge easily, are now used to a considerable extent.

THE ACID AND BASIC PROCESSES.

Phosphorus is the most difficult element to expel

from pig iron, by either the Bessemer or the open-hearth process. Though it combines readily with the oxygen and silicon to form slag, it is apt to let go its hold at the high temperature needed to decarbonize the metal and to recombine with the iron.

I must point out that the ganister lining used in the original Bessemer and open-hearth methods is an acid oxide—a non-metal (silicon) plus oxygen.

The *acid* process therefore implies the use of ganister. In the acid process the silicon of the ganister plus that in the pig iron practically prevents the phosphorus entering into the slag. The silicic acid ousts the phosphoric acid, and all the phosphorus passes back into the iron. So for many years it was necessary to use ores containing very little phosphorus, and as most English and German ores are highly phosphoric, both steel processes were seriously handicapped.

The discoveries of Messrs. Snelus, Thomas, and Gilchrist have led to the introduction of the *basic* process, in which the converter and hearth were lined with basic materials, limestone, and magnesia. (A base signifies a metal in combination with oxygen.)

It was now possible to use a highly phosphoric iron

in the converter, the phosphoric acid combining with the added lime to form a stable slag. But—and this is a matter of the greatest importance—the pig iron for the basic Bessemer converter had to be poor in silicon (which would attack the lining) and very rich in phosphorus to give the necessary heat by combination with oxygen (in the acid process the silicon is the chief heating agent); and, unfortunately, some English ores, while too rich in phosphorus for the acid Bessemer, are too poor in phosphorus for the basic Bessemer process. But, on the other hand, the basic open-hearth process could be used with iron containing any proportion of phosphorus, the heat being in this case supplied from outside. Consequently, in England and Germany, where ores containing a medium proportion of phosphorus constitute the bulk of the iron deposits, the basic open-hearth process is rapidly ousting the Bessemer process; while in the United States, where there are huge deposits of non-phosphoric ores, the Bessemer (acid) holds its own. As this last is the cheapest process, the United States has a decided advantage over European countries.

A peculiar and minor advantage of the basic process is that the slag, when ground up, makes a

valuable fertilizer for agricultural purposes, on account of the large proportions of phosphorus it contains.

Summary of Processes in the Manufacture of Iron and Steel.

ORES. (1.) Oxides of iron: non-phosphoric. (2.) Carbonates of iron: phosphoric.

PROCESSES. (A.) *Smelting.* Separates impurities. Product—pig iron.

(B.) *Conversion into pure iron* by puddling. All (practically) impurities removed.

(C.) *Conversion of bar iron into steel.* (*a*) By heating in carbon: cementation. Product—blister steel. (*b*) By melting bar iron in crucibles and adding carbon, or merely melting blister steel in crucibles to distribute carbon equally: Huntsman's process. Product—crucible or cast steel (of the highest quality for cutlery, tools, etc.).

(D.) *Conversion of non-phosphoric pig iron into steel.* (*a*) By acid Bessemer process; (*b*) by acid open-hearth process. Product—acid steel.

(E.) *Conversion of phosphoric pig iron into steel.* (*a*) By basic Bessemer process; (*b*) by basic open-hearth process. Product—basic steel.

ALLOY STEELS,

owing to their increasing application, deserve some notice.

Nickel steel contains from 3 to 3·5 per cent. of nickel and ·25 per cent. of carbon. Properties: very ductile; does not crack when penetrated or break easily when bent. Uses: for armour plate and shafts of screw-propellers, etc.

Manganese steel contains 12 per cent. of manganese and 1·50 per cent. of carbon. Properties: very hard, and yet ductile; cannot be softened by heat. Uses: for safes, rock-crushing rollers, railway crossings, etc.

Chrome steel contains about 2 per cent. of chromium and from ·80 to 2 per cent. of carbon. Properties: intensely hard and elastic. Uses: for safes and armour-piercing projectiles.

Tungsten steel contains from 5 to 10 per cent. of tungsten, and from 1 to 2 per cent. of carbon. Properties: when magnetized remains magnetic for a long time; is not softened by heat. Uses: for magnets and metal-cutting tools.

This and the two previous chapters may perhaps be considered somewhat heavy reading on account of their many references to chemical action. But as iron and steel are the materials out of which many of the

articles described in subsequent pages are made, and are of the highest importance commercially, I feel that it will be worth the reader's while to digest my brief outlines of the processes by which iron, that "king of the earth," is separated and modified for human use.

I am under a great obligation to Messrs. Brown, Bailey, and Co. and Messrs. William Cooke and Co. of Sheffield, for facilities afforded me to make personal acquaintance with the open-hearth, Bessemer, and puddling processes, and with various methods of rolling and shaping the metal so produced.

Chapter XVII.

ARMOUR PLATES AND BIG GUNS.

Messrs. Vickers Sons and Maxim's Works, Sheffield—Ingot casting—The rolling-mill—Reducing the thickness of a plate—Resistless power—A monster hydraulic press—Carbonizing armour plates—Bending plates—Shaping plates in huge machines—Hardening—Assembling the plates—Built-up cannon—Wire-wound guns—The ingot for the inner tube of a 12-inch gun—How it is forged and tempered—Shrinking a second tube over the first—Wire-winding—Interesting figures—Shrinking on the jacket—Rifling—The breech and its mechanism—A terrible weapon.

THE manufacture of the protection and armament of a battleship demands the employment of some of the most powerful machines to be found in the workshops of the world—monster cranes, huge presses, colossal lathes and planers. Any visitor to an establishment where armour plates and big guns are made cannot but be greatly impressed by the apparent ease and actual exactitude wherewith great masses of steel are shaped to suit the various purposes for which they are intended. Resistless power quietly applied is the dominant note of such a place.

No doubt the story of an armour plate, one of those great slabs of hardened steel that form the shell-resisting husk of our floating forts, will interest you; so I will do my best to narrate it as I learnt it, by eye and ear, at the River Don Works, Sheffield,

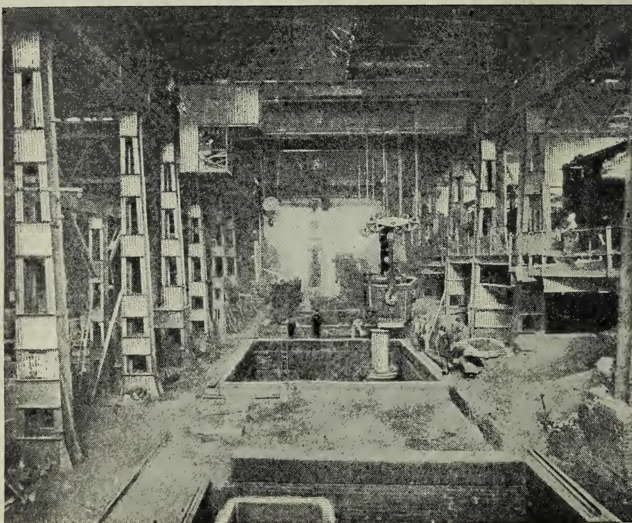


Fig. 104.—Pouring liquid steel into Ingot Moulds.

of Messrs. Vickers Sons and Maxim, the famous manufacturers of war materials.

The armour plate begins its existence as a great ingot weighing anything up to 60 tons. A spacious building, which covers as much area as would accom-

modate a full-sized football ground, is devoted to the steel-producing plant. Here we find nine open-hearth furnaces, in which 300 tons of steel can be made at one time. Close by are yawning casting-pits, 15 feet deep, wherein stand the ingot moulds, mouth upwards, each ready to receive the combined contents of several furnaces, which are transferred to them in huge ladles. The pouring of an ingot is a sight that one does not easily forget (Fig. 104).

The moulds into which the metal is poured from the ladles vary in form. For armour plates they are rectangular, cast in one piece, and weigh in some cases as much as 60 tons without their molten contents, which weigh as much more. The bottoms of the moulds are cast separately. At the top, where the metal enters, there is a big neck, which is filled as well as the body of the mould, to ensure purity in the ingot. The "runner" that occupies the neck has to be cut off the ingot subsequently for remelting.

After cooling for about twenty-four hours, a large ingot is removed from its mould to make room for another; but if it is very thick—say 45 inches through—it must stand for one or two days more before it is cool enough to be worked. An electric

overhead travelling crane then lifts it from the pit and lays it on a truck, which carries it away to

THE ROLLING-MILL,

towards which we will direct our steps. This stands in the centre of a shop, flanked by reheating furnaces, and, as usual, dominated by a powerful travelling crane. The mill itself has two solid steel rollers 3 feet in diameter and 12 feet long. The bottom one is fixed; the upper can be raised and depressed by a vertical screw at each end, operated simultaneously through a gearing driven by a separate steam-engine. Pointers travelling round dials at each side of the mill inform the workmen of the distance between the rolls. In an annexe is a monster engine of 3,000 horse-power for driving the rolls. A cog on its crankshaft transmits the power of the steam to a second and much larger cog, which is connected to the rolls by stout bars.

When it arrives from the casting-pits, the ingot to be rolled is placed on a car and thrust into a gas furnace and brought to a white heat. Then the car is moved out, and the crane lifts off the ingot and deposits it on a series of rollers arranged in frames in the floor on both sides of the mill, to

which they are geared. The rolls are adjusted to the proper width, and the signal is given to the man stationed on a platform in the engine-house. He moves one lever which decides the direction in which the cranks shall turn, and another controlling the steam-valve. The massive flywheel begins to revolve, the gearing clanks, and the plate is carried forwards by the floor rollers to the rolls, gripped, and pulled through resistlessly. As soon as it has passed, the auxiliary engine rattles, and the pointers on the dials move round through an arc which represents half-an-inch decrease in the distance between the rolls. The main engine is reversed and restarted, and the plate dragged through again. In a surprisingly short time a 36-inch ingot is flattened out into an 18-inch plate. (See Frontispiece.)

The rolling has caused the formation of "scale"—oxide of iron—on the surfaces of the plate. When the process of reduction is nearly completed, men advance with bundles of brushwood and throw them on. They catch alight instantaneously, and as soon as they encounter the pressure of the rolls they blaze furiously, enveloping the rolls and the framework in a roaring flame. When the plate returns, men armed with long hoes scrape off the cinder and such scale

as has been loosened. More brushwood is flung on, the flame rises again, the plate is re-scraped, and when this has been repeated several times the surface is clean.

The plate is now taken to the

HYDRAULIC PRESS,

an immense tool which stands over 40 feet high, weighs nearly 800 tons, and is able to give an 8,000-ton squeeze. It has two vertical hydraulic cylinders, 40 inches in diameter, with a 10-foot stroke. A mass of metal, shaped like an inverted T, takes the pressure of the rams working in the cylinders on each end of its cross. A very powerful steam-engine pumps water into the cylinders at a pressure of 2½ *tons* to the square inch when the press is in action.

A cutting tool attached to the under-side of the crosshead cuts off the "runner," and divides the plate into slabs varying in size according to the dimensions to which they will afterwards be finished. The slabs are then returned to the rolling-mill, reheated, and rolled out to the required thickness.

Then follows the very important process of

CARBONIZING

the surface intended to resist an enemy's shot and shell. This process is practically cementation (see

p. 242) on a very large scale. Special furnaces, into which cars carrying the plate can be run, are used for the purpose. The top of a car is covered with several layers of firebrick as a protection against the heat, and on these a series of firebrick flues are constructed for the plate to rest on. The plate having been laid in position, its upper face is covered with powdered charcoal, and on this is laid another plate, face downwards, so that the two may be treated simultaneously. Four walls are built round the plates, the car is pushed into the furnace, the door is closed and sealed, and the gas is ignited. The flames enter at the back of the furnace, pass over the top plate, under the bottom plate, and out into the chimney through openings opposite the ends of the car flues. In about a fortnight the steel and charcoal sandwich is "done," part of the carbon having being absorbed by the contiguous surfaces of the plates.

BENDING.

Next comes the bending of the plate to its final shape. This, in the case of the thickest plates, is effected in the 8,000-ton hydraulic press. Packing pieces are used above and below the plate, when placed on the anvil, to bend it to the required form,

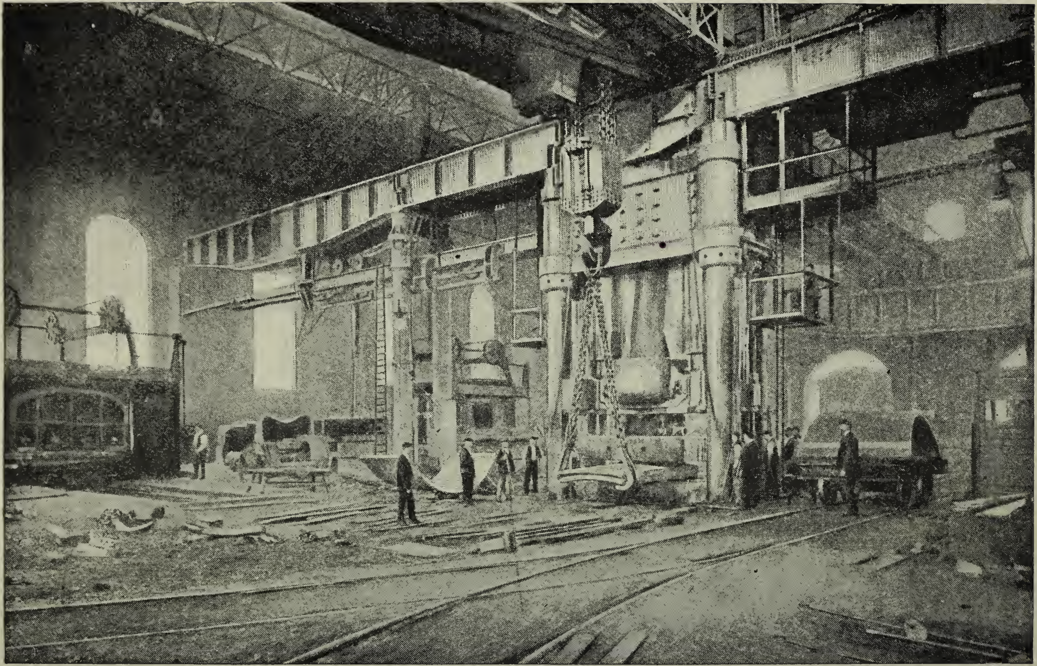


FIG. 105.—Bending an Armour Plate in a Hydraulic Press

and for plates of difficult bends special tools are provided. There is a second 8,000-ton press available for the same work, and a 3,000-ton press for dealing with the lighter armour plates.

SHAPING.

Our plate includes a large amount of superfluous metal, which must now be removed in the planing-shop, a building 150 yards long and 50 yards wide. Here we see a fine array of large planing-machines, each having a table weighing 30 tons, on which the largest objects can be treated. These machines cut strips off the edges of the plate, plane the edges either square or at an angle to the sides, and scrape the sides smooth. Then all necessary holes are bored in the carbonized surface by portable drills, have screw threads cut in them, and are plugged with clay. The extent of the work done to ensure absolute precision is indicated by the fact that the finished plates contain only one-third of the metal of the ingot from which they were made.

HARDENING.

The carbonizing of the plate was the first part of the hardening of the " business " face, a process which

necessarily cannot be completed until after all the requisite machining. To render the surface of adamantine hardness, the plate is heated in a car furnace and laid on an iron grid between two sets of sprinkling pipes perforated with a multitude of holes through which water is squirted at a pressure of 15 lbs. to the

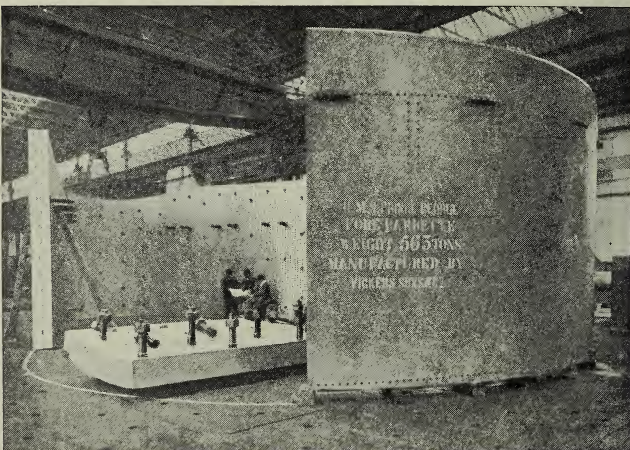


Fig. 106.—The Armour Plates for a Warship's Barbette.

square inch, to prevent the formation of steam on the surface of the plate. At the end of three hours, during which from 4,000 to 5,000 tons of cold water are used, the thickest plate is thoroughly chilled, and the carbonized face has become so extremely hard that a sharp steel punch struck by a 14-lb. sledge-hammer

makes absolutely no impression upon it. Consequently, if it should be found necessary to shape the edges after hardening, grinding machines must be used. Another method of hardening used is to drop the red-hot plate into a bath of oil.

The final process is the drilling and tapping of bolt holes in the non-hardened face, a comparatively easy matter.

Before they leave the factory for the shipbuilding yards, plates intended for turrets and gun-barbettes are assembled and adjusted till they fit as truly as the parts of a cabinetmaker's work.

BIG GUNS.

There would be no necessity for armour plates were there no big guns. The first are the logical complement of the second; and the struggle between the two goes on from year to year, as science discovers new explosives and new methods of toughening steel.

The earliest big cannon were made of cast iron, and were very feeble for their size as compared with modern artillery. In 1856 Sir William (afterwards Lord) Armstrong introduced the "built-up" gun, having a steel barrel reinforced by a succession of iron jackets shrunk over it and over one another from the

centre outwards. The jackets were fashioned out of wrought-iron bar coiled round a mandrel, and welded together under a steam-hammer.

His principle has been developed until we have the present high-velocity gun, steel-built throughout, with forged tubes and jackets and tough steel-wire wrappings. A glance at Fig. 107 will tell you how complicated is the structure of a modern 12-inch breechloading gun. Starting from the inside we

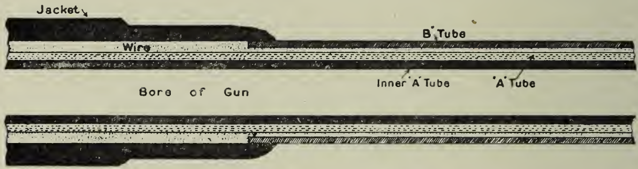


FIG. 107.—Section of a 12-inch Gun

have—(1) the inner A tube, which is rifled; (2) the A tube; (3) wire wrapping; (4) the B tube, extending for two-thirds of the length from the muzzle towards the breech; (5) the breech jacket.

The part to be made first is the inner A tube. For this a huge solid steel ingot is cast, weighing upwards of 30 tons. The ends having been cut off, the ingot is mounted in a lathe, and a tube-like "trepanning" borer removes a long core from the centre (Fig. 108).

The ingot is then dismounted from the lathe and

heated. A long hollow bar somewhat smaller than the destined bore of the gun is passed through the central hole; and the ingot is placed under a 2,500-ton forging press, which gradually thins and draws it out along the bar, which is kept cool by water circulating through it.

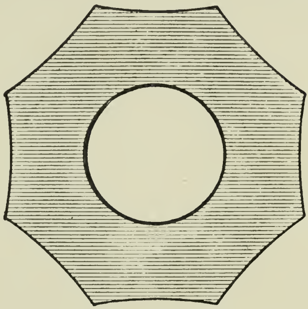


Fig. 108.—Gun Ingot ready for forging.

The forged tube is next rough-turned outside and rough-bored inside. It has then to be tempered. A huge 100-ton gantry crane seizes the tube by one end and lowers it into a vertical furnace heated by gas. Then it is drawn out and dipped into a deep vertical tank filled with many thousand gallons of cotton-seed oil, which gives it the required temper. This operation may have distorted the tube a little, in which case it is straightened in a special hydraulic press, preparatory to being bored and turned up again.

The A tube is made in like manner, and bored to an inside diameter slightly less than that of the inner tube. The inner A tube is let down into a pit, and the other, after being expanded sufficiently in the heating furnace, is lowered so as to slip over

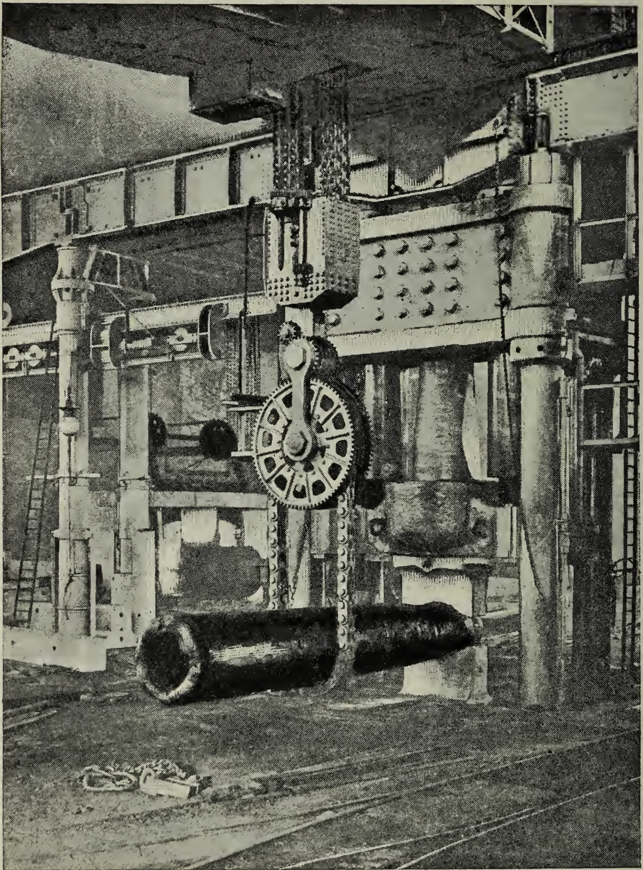


Fig. 109.—Forging a Gun Jacket in an 8,000-ton Hydraulic Press.

it. The heated tube decreases in length as well as in diameter as it cools, and unless great precautions

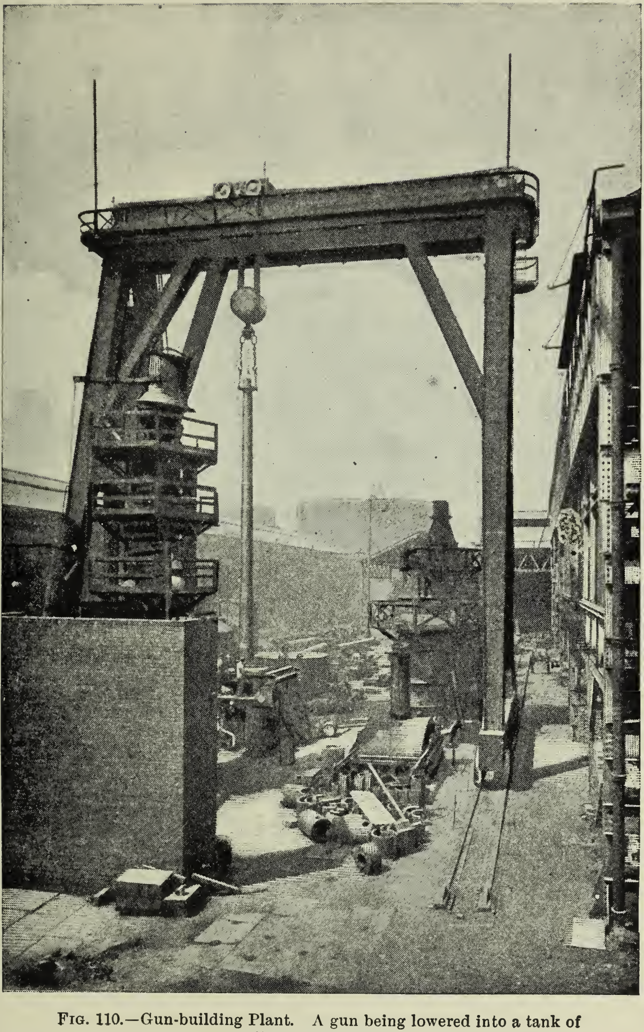


FIG. 110.—Gun-building Plant. A gun being lowered into a tank of oil to be tempered.

were taken it would naturally cool at the ends first, and, by gripping the "inner A" tightly there, cause the central part of the tube to cool in a state of dangerous tension. To avoid such a thing happening, one end is cooled artificially by means of water jets, while the other portions are heated by gas flames. The latter are extinguished successively to allow the tube to shorten gradually from the free end.

After the A tube has been turned up, it is "wire-wound" with a ribbon of steel $\frac{1}{4}$-inch wide and $\frac{1}{16}$ of an inch thick, tested to a tension of 110 tons to the square inch of section. This wire is coiled on a drum supported by a carriage travelling the whole length of the lathe. As the wire comes off on to the gun, the carriage is moved along at such a pace that the coils touch one another laterally as they are formed round the tube. A 12-inch gun is wound with fourteen layers at the muzzle and seventy-five at the breech, the total length of wire used being about 117 miles—the distance from London to Bristol—and its weight nearly 14 tons. It is necessary that the tension of the wire should decrease with every successive layer to avoid undue stress. This is effected by passing the wire, as it is unwound from the reel, through dies of hardened steel with slightly curved

surfaces. The dies are pressed together by a series of levers and weights, and by altering the positions of the weights the tension can be adjusted exactly.

After wiring, the surface undergoes "skimming" to

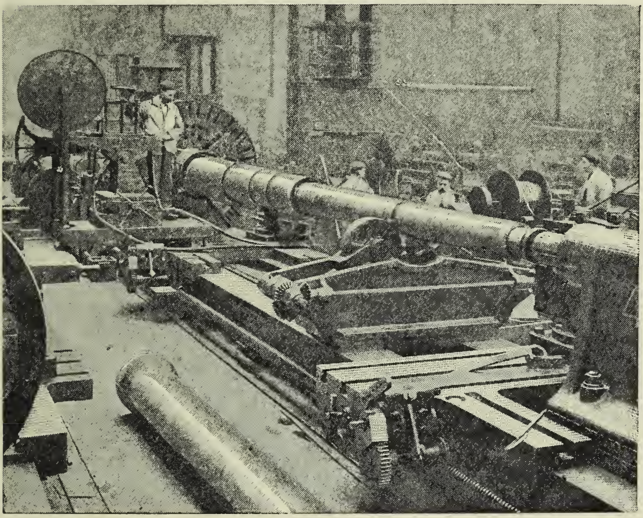


FIG. 111.—Winding Wire on a Big Gun.

ensure perfect truth, and the B tube, which has been prepared meanwhile, is shrunk on in the manner already described; and the breech end is similarly encased in its stout jacket. The A and B tubes and the jacket give the gun longitudinal stiffness, and

the wire greatly increases its strength circumferentially.

RIFLING.

Having been bored once more and finally, the gun is fit to have the spiral rifling grooves cut in the bore. These, as you doubtless know, are necessary to give the shell the spin which prevents it from turning head over heels during its flight through the air.

The rifling is done by a long, hollow steel rod, which carries three tools at the end to cut three grooves at once. The tools act only as the rod is withdrawn. To impart to them the twist necessary to produce a spiral cut an ingenious device is employed. Alongside the bed of the machine on which the rifling-rod runs is a bar arranged at an angle to the rod, the distance between the two increasing towards the rear. A cog fixed to the rod engages with a rack attached to a carriage on the bar, which slowly revolves the cog as the rod is pulled out of the gun, since the rack necessarily has to move across the rod as its fixed end recedes from the rod's axial line. If the rifling has a constant "pitch"—that is, twists the same amount per foot right down the barrel—the guide bar is straight, but curved if

the twist has to become gradually more pronounced towards the muzzle. As soon as one set of grooves is finished the gun is partly rotated, and fresh surfaces are exposed to the tools. A gun has, speaking roughly, two grooves to every inch of the circumference of the bore, so that in a 12-inch gun about seventy-five grooves would be cut. Eight to a dozen journeys of the tool are required to finish a groove, therefore the slow-moving cutter may have to be drawn out and thrust in some nine hundred times before the rifling is complete. As the rifling comes so near the end of the manufacture of a big gun it must be conducted with the greatest care, for a single badly-cut groove would spoil the gun, now representing perhaps £10,000 in work and material. We may here remark that extreme care and accuracy characterize every process of making heavy ordnance. The steel for the tubes is made carefully; the ingots are cast carefully and forged carefully. Every tube is bored and turned to a minute fraction of an inch, the final boring of the inner A tube requiring no less than three separate cuts, the last of which removes a layer only $\frac{1}{500}$ of an inch thick maybe. Though a 12-inch gun is nearly 20 inches thick over the powder-chamber, each of its various jackets must

have its proper tension in order to receive its fair share of the shock of explosion.

The bore being finished, the breech end is chambered out, and has deep threads cut in the rear end for the breech block to engage with. The block moves on a hinge, and is a very massive affair, though, thanks to the presence of certain levers and the perfection of the workmanship, any one who has the knack can move it quite easily. The pressure of the exploding powder is so great that gas will pass the most carefully-made block unless it is furnished with an "obturator pad," a flat circular canvas bag attached to the inner end. The gas squeezes this up against the block so tightly that it expands sideways with such force as to seal effectually any cracks between the block and the walls of the chamber.

From first to last a 67-ton gun takes about a year to construct. The mountings, which are made simultaneously with the gun, are of too complicated a nature to be described here in detail. When all the parts come together, the gun undergoes a firing test, and if these are satisfactory, is handed over to the purchaser, to be mounted in a land or floating fort, and help to maintain peace by its capacity to do

terrific damage to any hostile ship; for woe betide the object that impedes the flight of a half-ton projectile moving with a velocity of 25 miles a minute, and with a striking energy of over 22,000 tons!

[*Note.*—The photographic illustrations to this chapter were kindly supplied by Messrs. Vickers Sons and Maxim.]

Chapter XVIII.

SAWS AND FILES.

Various kinds of saws—Grinding a saw—Hardening and tempering —Polishing—Finishing—Fitting the handle—Files—Varieties of files—Rasps—Forging—Grinding—Cutting the teeth—An ingenious machine—Hand-cutting—Tempering—Testing a file.

THE manufacture of saws is an important industry on account of the great number of purposes for which saws of various types are needed. The chief classes of saws are—(1) the flat, straight-edged; (2) the disc or circular; (3) the endless or band. They are made in all sizes, and toothed and tempered to suit the work that they have to do. For cutting extremely hard substances, such as granite, diamond teeth are sometimes fitted. The largest circular saws, used to slice off very thin sheets of wood for veneer, have a diameter of from 15 feet to 20 feet, and are extremely thin. A steel-plate-cutting "circular" has a very thick blade and much smaller teeth than a wood-cutter of the same diameter.

Good saws are made from the best crucible steel. Ingots of this are rolled out into square sheets of the required thickness, and the blank saw is stamped or cut from the sheet. It is then placed in an automatic machine, which shapes out the teeth with a steel cutter or emery wheel.

FIG. 112.—The projections outside and the indentations inside the ring-plate show different shapes and sizes of teeth.

GRINDING.

Flat saws are ground between two circular grindstones, one hard and the other soft. The soft stone revolves more slowly than the hard one which does the grinding, in order to retard the saw and give the other stone time to act. The grinding-stone has

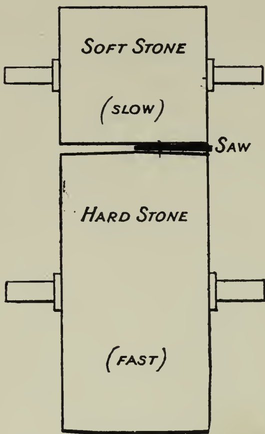


FIG. 113.—Stones for grinding a Saw.

a conical face (see Fig. 113). The blade is fed in at one side of the stones with its teeth outermost, and is consequently slightly tapered towards the back, where the stones are nearest to one another. This tapering enables the saw to move in a cut without friction. When one face has been ground, the blade is turned over and passed through the stones on the other side.

Circular saws are ground on flat tables by a disc grinder, which has a conical face if the saw requires thinning towards the centre.

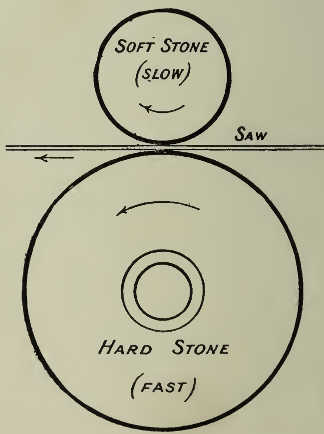


FIG. 114.—Side view of the same.

HARDENING AND TEMPERING.

The blade, after being ground, is heated to redness

and plunged in water. This renders the metal very hard and brittle; so it is reheated to about 800° F., which gives it the necessary temper or elasticity. Circular saws are laid between two perforated plates while being tempered, to prevent twisting and warping under the heat. But however great be the care taken, they are more or less distorted, and have to be flattened by hammering. The workmen employed to do this lay a saw on a flat steel table, and strike any curved part on the concave side with a sharp-pointed hammer. The blow slightly stretches the metal sideways and flattens the curve.

POLISHING,

which follows, is done in much the same way as grinding, the grindstones being replaced by wooden rollers or discs faced with leather, which has a beeswax dressing to hold the emery powder used to brighten the saw.

Hammering and polishing take some of the temper out of a saw. If bent severely, the blade does not regain its shape. To restore the temper, the saw is buried in a thin film of sand spread over the bottom of a special furnace and allowed to remain there for a short time. The slight discoloration caused by the heat is

removed by rubbing the saw over with dilute hydrochloric acid, which in turn is washed off with lime-water.

The saw is now ready for having its maker's name, trade-mark, etc., etched on it by acid, and being fitted with a handle or spindle for use. The ordinary carpenter's saw-handle is made very quickly. Its outline is stamped on a piece of beechwood, and cut along by a band-saw. A drill pierces a hole in the centre, for the introduction of a large fretsaw, which roughs out the space for the fingers. The sides are then smoothed by a large circular plane, resembling in its action a mangold cutter, and all edges are rounded off by a vertical milling tool projecting from a steel table. A boy then goes over it with a file, polishes it, and bores the screw holes, with depressions to take the heads of the screws. Finally, it is placed in two self-centering jaws and pressed up against a circular saw, which makes a central cut to admit the blade.

Most saws have their teeth "set"—that is, bent slightly to one side or the other alternately—before they leave the factory.

FILES

may be described as round, semicircular, triangular, or flat bars of steel, with their surfaces corrugated by a series of parallel ridges produced with a chisel. These ridges usually lie at an angle of about 55° to the long axis of the file.

Some files have only one set of parallel ridges. These are called "single cut" or "float" files, and are used mostly for working copper, brass, and other soft metals. Files employed on iron and steel are "double cut," a second series of ridges being superimposed on the first, with the slope in the opposite direction (Fig. 115). The effect of double cutting is to break up the surface into a number of sharp points. Files are known as "rough cut," "middle cut," "bastard," "second cut," "smooth," and "superfine," according to the size and finish of their teeth. A *rasp* differs from a file in having large detached teeth made with a punch instead of with a chisel.

FIG. 115. — "Double Cut" and "Single Cut" Files, and a Rasp.

Most square-cornered files taper towards the point, to allow the workman to make a flat cut with greater accuracy, the curving taper counteracting the slight change in the elevation of the elbows as the arms are worked to and fro. The circular file is commonly tapered so that it may enlarge a hole.

The material used for files is cast steel. Bars of the proper section are forged roughly by hand, softened, and ground smooth on stones to the finished shape. The last operation requires the exercise of considerable skill to maintain the proper taper, or to avoid taper in the case of a parallel-sided file. They are then handed over to the cutters.

CUTTING

is done in a machine or by hand. The machines used for the purpose are very ingenious. The blank to be cut is laid on a bed, which advances automatically a certain distance between every two blows of the chisel. The chisel is raised by a cam and depressed for the cutting stroke by a powerful spring, the tension of which can be regulated to make a nick of the required depth. The chisel delivers about one thousand blows a minute.

Round and triangular files are bedded in a groove

in a lead plate while being cut. A curved surface is treated in a series of "courses," the file being partly revolved after every course, so as to expose a fresh surface to the chisel. Twelve courses and upwards are needed for a circular file.

Double-cut files cut on the earlier types of machine had the fault of too great regularity. The scratches made in a piece of metal by the teeth at the beginning of the stroke were gradually deepened as the file advanced, because the teeth stood in exact lines, one behind the other; whereas the irregular teeth of a hand-cut file acted on the whole surface, one tooth removing what another had missed. For this reason there was, and still is, a prejudice against the machined file and a preference for the hand-cut. Machines have been recently introduced, however, which give the necessary irregularity of cut.

The hand-cutter usually works at home. His outfit consists of a few anvils and a set of chisels. He lays the blank to be treated on an anvil with the "tang," or handle-point, towards him, and passes a strap over each end and under his feet to keep it steady. In his left hand he holds a chisel of the same width as the file, and resting it on the tip of the file with its top end sloping somewhat away from

him, he makes a stroke with the hammer. The chisel as it sinks into the metal raises a slight ridge on the tang side of itself. The workman lifts the chisel, rests it on the uncut surface, and pushes it away from him until it is stopped by the ridge. Then he makes a second stroke. In this way each ridge acts as guide for the succeeding cut. A good workman is able to cut a hundred nicks per minute, and by long practice proportions the strength of the blow to give a nick of the exact depth required for any kind of file. Though machinery has replaced hand labour in almost every industry where very fine work has to be done, the hand-worker holds his own in the file trade so far as the cutting of the smallest files—locksmiths' and jewellers'—is concerned.

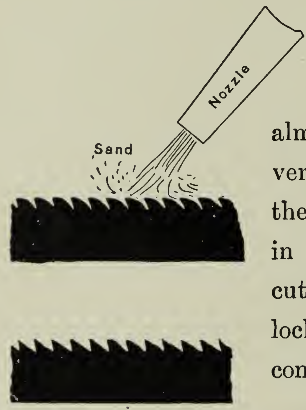


Fig. 116.—Teeth of File being sharpened by sand blast (above); teeth after sharpening (below).

After being cut, the file is heated, hardened by a plunge into brine, and tempered. While still hot from tempering it is straightened by having cold water thrown on the convex side of a curve.

The teeth have now to be sharpened by sand-blasting. The file is introduced through a slit into a chamber wherein it is exposed to a jet of sand projected through a nozzle by high-pressure steam. The sand strikes the teeth on their rear surfaces, and causes an alteration in shape, which will be understood by reference to Fig. 116.

TESTING

is twofold. First, the file is struck on an anvil. If it "rings true," it is uncracked and sound. Secondly, it is rubbed over a piece of steel. If any part is soft, it slides over the steel without biting, and is easily detected by its polished appearance, due to the teeth being bent over and burnished by the steel.

Chapter XIX.

HOW A WATCH IS MADE.

Coventry and its watch industry—A watch the embodiment of mechanical delicacy—Parts of a watch—A funny story—The metric system—The watch case—Engine-turning—The dial—Writing extraordinary—"Sunk seconds"—The "movement"—The train wheels—The pinions—Extreme accuracy of workmanship—The escapement—Making the balance-wheel—Levers, pallets, and escape-wheel—Assembling the parts—Jewels—A wonderful performance by a watch—The hairspring—Timing a watch—Kew Observatory tests—Saving gold dust—Men who have stuck to their work.

COVENTRY is one of the most interesting cities in the British Isles. It has a romantic history, which includes the well-known episode of Lady Godiva; contains many fine and ancient buildings, and wide, clean streets; and is the seat of several important industries, notably those of watch, cycle, and motor manufacture. In fact, the Coventry of today is mainly devoted to "making the wheels go round."

Its watch industry, which dates from the seventeenth century, grew steadily till about 1860, when, as the result of keen competition with Switzerland

and the United States, it became greatly depressed, and was revived only by substituting for the domestic workshop the more modern machine methods and the exactly-organized factory. Even if it does not hold its former pre-eminence for quantity, Coventry still turns out great numbers of watches, many being of the very highest quality that money can command.

A watch is so wonderful and dainty a machine, and so familiar an object to all readers, that it will be only fit and proper to devote a good long chapter to the processes through which metal has to pass while being shaped into a complete pocket timepiece. "Made like a watch" is a phrase used to denote the utmost accuracy and delicacy in construction, but its full truth is appreciated only after you have actually seen the shaping and fitting together of the many dozens of parts that go to make up a watch.

As want of space prevents me from here describing the mechanical principles of a watch, I would refer the reader to chapter xx. of "How It Works," which explains matters fully. It must suffice to mention that the motive power is a spring, the unwinding of which turns a train of wheels whose revolutions are controlled by the escapement, this last consisting of a balance-wheel, on which is a hairspring constantly

rolled up and unrolled by the pressure of the teeth of the last wheel in the train (called the escape-wheel) either against the pallets of a lever operating the balance-wheel, or directly against a tiny cylinder mounted on the axle of the balance.

I made my first acquaintance with a watch "in the making" at the factory of Messrs. J. Rotherham and Sons, where some five hundred "hands"—more accurately, one thousand—were hard at work on all manner of types, ranging from the agricultural labourer's "turnip," which has a separate outer case, to a tiny lady's watch less than an inch in diameter. The manager told me an amusing story about the incredulity of an employee who was informed, when the factory system was first instituted, that henceforward machines would be used to make everything accurately to within a thousandth part of an inch. "There aren't a thousand parts in any inch," said the man, quite unconscious of the fact that he himself had constantly been using the most microscopic measurements. To-day, by-the-bye, the metric system is in vogue at this factory. The men talk of millimetres and fractions of millimetres, not of parts of an inch. It will be a happy day for English industries when the same thing can be said of all factories, and we fall into line with other great manu-

facturing nations in this respect. As a writer, however, I prefer to keep to the inch in this chapter, to avoid mystifying readers who have as yet no knowledge of the metric scale.

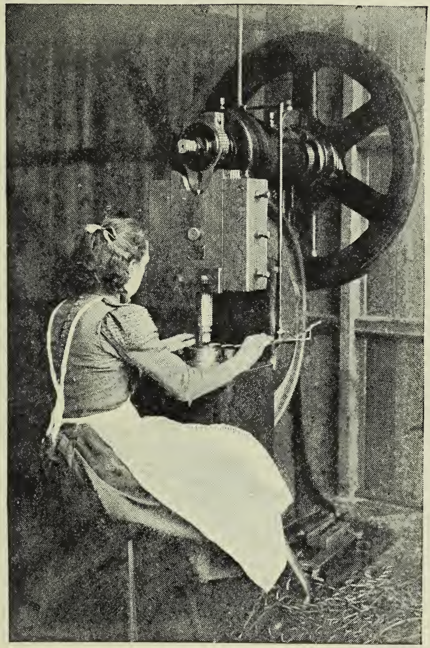


FIG. 117.—Stamping out Discs for Watch Cases.

THE WATCH CASE.

One part of the factory reminded me of the Mint, with its furnaces and machines for melting and rolling

gold and silver, and other machines for stamping the case backs out of strips of metal. The backs and bodies and fronts (for "half-hunters," these last) are moulded into shape by powerful presses, turned up in lathes, sent to London or Birmingham to be hall-

FIG. 118.—Engine-turning the Case of a Watch.

marked, beaten smooth on a little anvil, and fitted with a pendant (or knob), hinges, and spring for opening the back or face. Some watches have their backs engraved and then "engine turned," or patterned with a maze of little cuts, in a lathe fitted with a mechanism which jars the cutting tool, and so causes

it to dig a series of tiny, equally-spaced depressions in the metal as it revolves. A circle being completed, the tool is moved a trifle farther from the centre, and another circle is made, and so on till the process is finished. After a good polishing, a piece of tissue-paper is pasted over the back to protect it from being scratched while the works are inserted.

THE DIAL

is a very thin copper plate turned up slightly at the edge, so that the coatings of white enamel may not run off when the dial is baked to harden the enamel. Two coatings are applied, and then the surface is rubbed on a stone to prepare it for the figuring, which includes the hour and minute divisions, hour figures, maker's name, etc. When a large number of dials similar in all respects are to be treated, the various black marks are printed on by means of a very delicate pneumatic pad. But at Messrs. Rotherham's factory so many different sizes are made that hand-painting by a very skilled workman is the rule.

He uses his tools—tiny camel-hair brushes, fine as needle-points—with amazing dexterity. First he rules off the minute divisions, four shorts and a long—

the long for an hour—four shorts and a long, all round the dial, by the aid of a mechanical divider. Then he draws two fine circles close together with a

FIG. 119.—Printing the Figures on the Face of a Watch Dial.

pair of compasses, and paints in the divisions between them. Next go on twelve dabs of paint, which are cleverly scraped away to give the Roman numerals,

or else the Arabic numerals are painted on direct. But the masterpiece is the maker's name, formed, in one dial that I examined, of capitals less than one-fortieth of an inch high! These are painted in "freehand" between faint parallel lines.

After the figuring, the dial is baked a third time to set the black enamel, and give the white a smooth, shining surface. The final process is to drill out a hole with a conical reamer over "6 o'clock," and to paste behind it a "sunk seconds" dial. This last is printed, and is sunk below the surface of the main dial, so that the seconds hand may not come into contact with the other hands.

We now pass to another shop where

THE MOVEMENT

is being made. "Movement," curiously enough, is the term applied to the two *fixed* brass plates between and in which the pinions, or axles of the wheels, revolve. The plates are held apart by three pillars, the holes for which are drilled in an automatic machine. Many other small holes are drilled in the plates through templates or patterns fitted over the surface to be bored. No fewer than twenty-eight of these patterns have to be kept in stock for watches

of different sizes. Their use ensures the holes being in their right positions.

The "blanks" for

THE TRAIN WHEELS

are stamped out of thin sheet brass. A number of blanks are strung on a pin and held tightly together

Fig. 120.—Electroplating brass parts with gold.

in a lathe, while a diminutive circular saw runs along the surface, cutting out a groove. As soon as it reaches the end of its journey the lathe gives a click, and the cylinder of blanks moves round a little way.

Then a second groove is cut, and another, and another, until instead of the blanks there is a set of beautifully-toothed wheels. So delicate is the machinery that from seventy to eighty grooves are cut with the greatest accuracy on the circumference of a blank less than half an inch in diameter, the last of the series coming into its proper place relatively to the first.

The wheels have their sides polished to rid them of the "burr" of the cutter, and then, like all the other brass-work of a watch, are immersed in a gold electroplating bath, and undergo a rubbing which gives them a slightly rough but very pleasing surface (Fig. 120).

THE PINIONS,

or axles on which the wheels are mounted, are perhaps the most interesting parts of the works of a watch. They are turned out of steel wire in tiny lathes which, though they could almost be packed in a silk hat, are equipped with most of the gear found in large machines. Some, in fact most, of the pinions include a very small cog-wheel, which has to be toothed separately in a special automatic cutter. The ends are then fined down to hair size to fit the holes of the jewels in which they revolve. For

this process, as for most others in watchmaking, the operative has to use a magnifying glass, since the points are so small as to be almost invisible to the naked eye. To give exact figures, the smallest pivots are only $\frac{7}{1000}$ of an inch in diameter, and they must not vary from standard size by more than $\frac{1}{4000}$ of an inch.

THE ESCAPEMENT.

The manufacture of the "compensated" balance-wheel is also very interesting, because the thin rim of the wheel has to be compounded of

Fig. 121.

an outer strip of brass welded to an inner strip of steel (see "How It Works," page 423 *et seq.*). The workman is supplied with a number of steel blanks, each having a deep groove cut in it near the

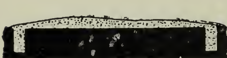


Fig. 122.

circumference (Fig. 121). He takes the blanks, sprinkles them with borax, fills up the grooves with brass filings, and places them in a furnace, where they remain till the brass has melted and run into the

Fig. 123.

grooves and welded itself to the steel (Fig. 122). The backs and fronts are turned in a lathe—the

backs until the brass in the grooves has been bared, so that you see on both sides a steel centre and two exterior bands of brass and steel. The outer steel band is removed, and the inner circle thinned down from both sides, all except a narrow band next the brass. Then the blank is put into a press which stamps out all the steel circle except two arms (Fig. 124) pierced by a central hole. The compound rim is now cut through in two places, near the end of the arms, and has a number of holes bored in it for the insertion of tiny screws, by means of which its balance is adjusted.

Fig. 124.

The wheel has to be mounted on a pinion, on which is also a very thin circular plate called the roller (see Fig. 125), notched at one point and furnished with an impulse pin I.

The levers and pallets are stamped out of sheet steel. The faces of the pallets would be worn away by the teeth of the brass escape-wheel were they not protected by very thin flakes of ruby let into grooves cut in them with a fine saw. This and the grinding down of the ruby are, as you may imagine, very delicate operations. Every lever and pallet is well

polished on both sides, and then a pallet is attached to each lever.

The escape-wheel is shaped out of a brass blank by a cutter revolving four thousand five hundred times a minute. Twenty-one wheels are treated at once. The

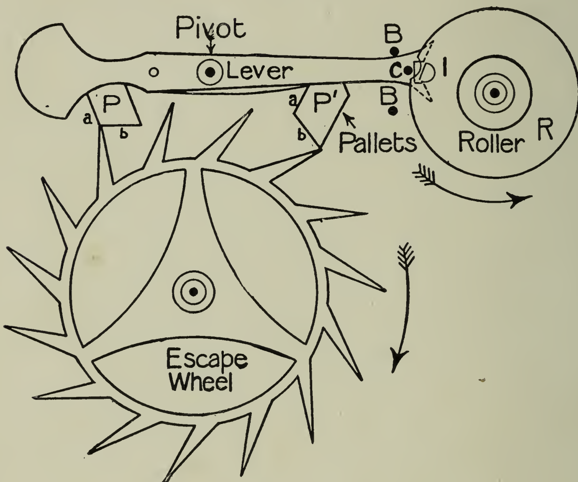


FIG. 125.—Lever Watch Escapement.

cutter has small steel points to remove the brass, and sapphire points to polish the sides of the fifteen teeth. It is quite fascinating to watch the metal being eaten away and the sharp projections gradually taking shape.

ASSEMBLING THE PARTS.

The many different parts are put together by very

skilled workmen. First comes the "jewelling" of the holes in the movement plates. Each jewel is a minute circular ruby, garnet, or sapphire disc, in which a diamond drill has pierced a microscopic hole of sufficient size to accommodate the end of a pinion. The hole is not cylindrical, but tapers from each end towards the middle, so that the axis of the pinion rests only on an edge (Fig. 126). Each jewel is fixed in the

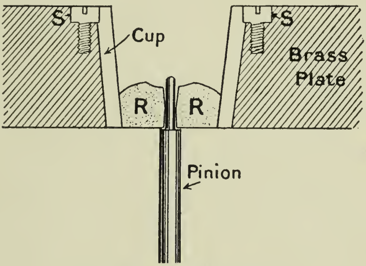


Fig. 126.—Jewel and Pinion.

bottom of a collar shaped like a flower-pot, and the flower-pot is held in its hole in the movement plate by two screws. These screws are Lilliputian indeed, the smallest having heads only $\frac{3}{100}$ of an inch across, and a thread sunk $\frac{2}{1000}$ of an inch deep in the shank. But they are made exactly to gauge, and the holes for them are truly bored and duly "tapped." The balance-wheel pinion jewels, being subjected to most wear, are, in the highest-class watches, small diamonds.

So perfect is the adjustment of the balance-wheel that when riding loose in its jewels a gentle tap will make it revolve hundreds of times with the ease of a cycle wheel running on ball bearings. The balance of the watch which I have in my pocket at the time of writing this has travelled about 60,000 miles without any appreciable wear to either jewels or pinions.

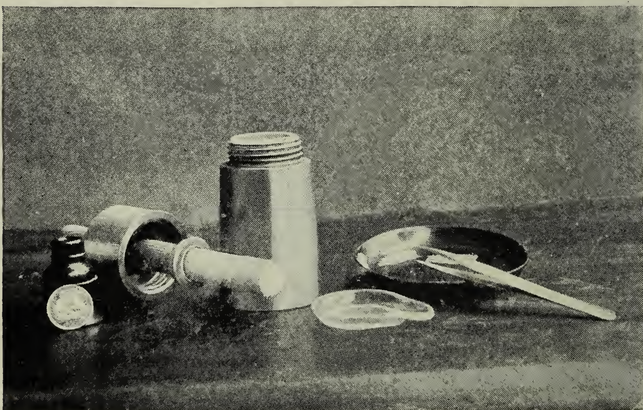


Fig. 127.—Apparatus for grinding Diamonds.

The winding gear having been attached to the movement, the mainspring, wheel train, dial, hands, and escapement are placed in position. The mainspring is wound up, and the watch is made to run on "half-time"—that is, without the checking action of the hairspring on the balance-wheel. If it goes

properly, it is handed over to the "springer," who attaches the hairspring, a coil of the finest flat steel wire imaginable. The majority of hairsprings used in England are imported from Switzerland, where their manufacture is an important industry. In order to keep the convolutions of the spring properly spaced during the tempering process, the springs are arranged in sets of two, three, four, or more, according to the closeness of the convolutions, wound up one inside the other.

When the springer has poised the balance-wheel with the rim screws already mentioned, he "times" the watch and hands it over to the testing department. There it is run one day in a vertical and one day in a horizontal position, against a chronometer corrected daily at 10 a.m. to exact Greenwich time. If it keeps time within certain limits, it is "passed" to the storerooms; but if unsatisfactory, it goes back to the springer for further adjustment. The best watches undergo special tests at the Kew Observatory, lasting forty-five days. They are placed in several positions, in hot ovens and refrigerators, to prove whether the "compensation balance" does its work properly. Each returns from Kew accompanied by a certificate of merit, setting forth the

amount of variation from perfect time in different temperatures. An "A 1 Kew certificated" watch is a very good watch indeed.

In a factory where gold is handled in considerable quantities great care has to be taken to waste as little as possible of the precious metal. The dust on the floors is collected and put into the melting-pot; the water the employees wash their hands in is saved; their aprons are wrung out into water, and that is saved too. Furthermore, people buy the soot from the chimneys of the melting-furnaces and extract gold therefrom.

A remarkable thing about Messrs. Rotherham's factory is the manner in which some of the employees have stuck to their benches. On the wall of the office hangs a photograph of a group of seven men—one a head of the firm, the other six old workmen—who had been in the service of the firm for over fifty years.

I do not propose to give any description of clock-making, as it has many processes in common with the manufacture of watches, but does not need the same amount of skill.

[*Note.*—The author is indebted to Messrs. Geo. Newnes, Ltd., for the illustrations used in this chapter.]

Chapter XX.

IN A MOTOR-CAR FACTORY.

The rise of the motor car—A factory laboratory—Testing metal—The drawing-office—The tool-shop—High-speed steel—Shaping a crankshaft—Working to exact measurements—Grinding metal to size—Need for accuracy—Boring a cylinder—The components fitting-room—Testing an engine—Assembling the parts of a car—Electroplating—A time-registering clock.

WE now come to the most recently-established of the industries to which Coventry is given over—namely, the building of motor cars. For some years past several leading cycle firms have divided their attention between the cycle and the automobile, and produced very creditable vehicles. But so great has become the demand for motor cars that a number of factories have been opened, or are in course of erection, or are projected, for the purpose of manufacturing cars, and cars only.

To one of these last—that of the Daimler Company—the writer went in search of information, and was courteously allowed admission to all the workshops

of the large and well-equipped group of buildings owned by the company, wherein some two thousand five hundred workmen earn their daily bread.

To take things in their logical order, I will begin with the laboratory, in which every "delivery" of steel, aluminium castings, etc., has to pass searching tests before being allowed to enter the shops. The chemical and physical properties of the material of every metal part of a car being thus checked, it is possible to guarantee uniformity and to guard against those mysterious breakdowns which are apt to make the automobilist a very miserable man for a time.

Chemists ascertain by analysis what the exact chemical nature of a metal is, or polish a surface and subject it to the searching scrutiny of the microscope to determine whether its crystallization takes the desired form. Powerful machines stretch, compress, and bend the metal; and there is also an apparatus with a heavy pendulum, which bangs down against a steel test-piece, and decides whether the delivery from which this sample was taken is capable of withstanding the sudden shocks to which all motor cars are subjected on the road. The strength and resiliency of the springs are also carefully investigated.

In the drawing-office the first practical work towards producing a car is done. The engineers having made up their minds as to the design, power, etc., of a car, skilled draughtsmen produce very careful drawings of all the parts, some full sized, and some on a reduced scale, for the guidance of the workmen. As in the watch trade, so here, the metric system has been adopted in its entirety.

The tool-shop is the first of the constructive departments. Here many tools are made for use in the machine-shops; and since the quality of the car depends to a great extent on the accuracy with which its parts are constructed, and accuracy of construction largely on the precision of tools, it is in this shop that the most highly-skilled workmen are needed. Cutting tools are made from "high-speed" steel, a comparatively recent invention which has, it would not be too much to say, almost revolutionized some manufactures and greatly reduced the cost of production. To show the importance of the invention, let us suppose that a steel shaft has to have its diameter reduced $\frac{1}{4}$-inch by a single cut $\frac{1}{8}$-inch deep. Were a cutting tool of ordinary crucible steel used, we might find that if the shaft revolved more than forty times a

minute, the point of the tool would become so hot as to soften and be useless. But if a high-speed tool be substituted, the lathe may be "speeded-up" to perhaps four hundred revolutions a minute, and the job will be done in one-tenth of the time.*

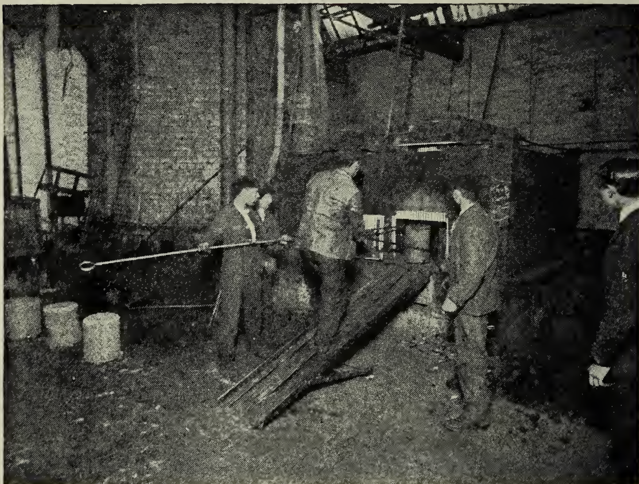


FIG. 128.—Case-hardening the parts of a Motor. See page 329.

Result: wages saved; work done more promptly; more money earned by a machine in a given period. With an "A. W." (Armstrong-Whitworth) high-speed twist drill it is possible to bore through cast iron at the rate of twenty-five inches a minute, and main-

* This increase in the speed has actually been attained.

tain the speed for some hours before the drill loses its edge.

After this digression we may turn our attention to the machine-shop, which is divided into different departments, each devoted to a particular kind of

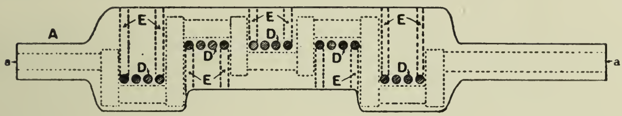


FIG. 129.—A Crank in the rough. The fine dotted lines show the crank that is to be.

work. Here is a rough forging shaped as shown in Fig. 129. Let us see what the workmen are going to do with it. First, it is mounted in a lathe, and has its ends A A turned. Then it goes to a planing-machine, and the sides are scraped flat.

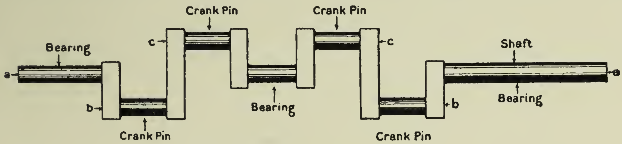


FIG. 130.—The finished Crank.

Next, five rows of four holes each are bored through it by a drill (D D, Fig. 129). A slotter then cuts it along the dotted lines E E. The parts between the slots are broken away, and finally it is placed in a lathe and revolved with *a a*, *b b*, and *c c* successively

on the centre line; and, behold! we have a four-crank crankshaft in the rough—for the seven circular parts have to be reduced to within $\frac{1}{3000}$ of an inch of their standard diameter by a whirling emery wheel. The finishing touch is given to shafts in the same way, but in their case a deviation from standard of $\frac{3}{5000}$ of an inch is permitted. The reader may perhaps be at a loss to understand how a grinding-wheel can be made to do such delicate work, and how the workmen can keep to such very narrow limits. Let me explain. He has a double-ended gauge, shaped somewhat like two horseshoes attached back to back. The opening of one horseshoe we may assume to be exactly two inches across, that of the other two inches *less* $\frac{1}{1000}$ of an inch. If a shaft is reduced till it will pass through the one opening but not through the other, its diameter must be within $\frac{1}{1000}$ of an inch of truth. The one measurement is the *maximum*, the other the *minimum*, permitted.

The object to be ground is slowly revolved, and the wheel, turning very fast, is moved quickly to and fro from end to end of it. The wheel therefore remains at any one spot of the surface for an exceedingly brief period, and removes very little metal from it each journey. Its effect is constantly

checked by the maximum end of the gauge. As soon as the shaft is able to pass this, but not the minimum end, at any point, the process is considered complete.

This standardization of parts has been reduced to a fine art. Both from the manufacturer's and

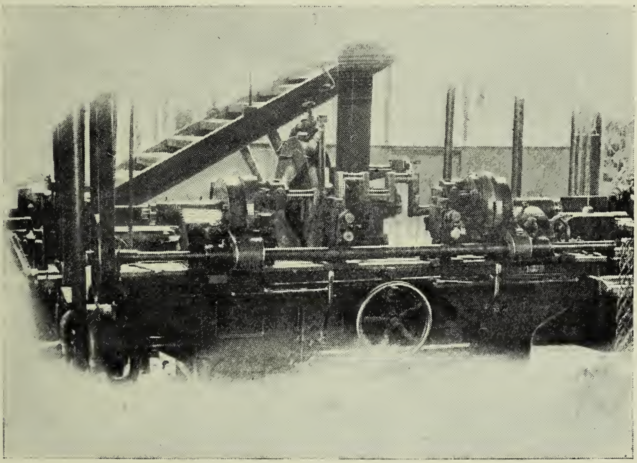


FIG. 131.—Turning a Crank.

the customer's point of view interchangeability is essential. For the former it makes the assembling of parts a simpler process, and for the latter it ensures easy replacement of worn and damaged parts.

When a part is finished it is inspected, tested, and sent to one of a number of storerooms.

We may now return to the machines and watch the shaping and boring of a cylinder. The first process is to plane the surfaces which touch the crank case, and to which all pipes, etc., are attached. This is done in a "jig" furnished with circular milling cutters, moving backwards and forwards in a straight line. As soon as the outside has been machined, the inside of the cylinder is bored on a lathe. The first—the "rough"—cut removes nearly all the superfluous metal, the second—the "finishing"—enlarges the bore to standard size. A very ingenious micrometer gauge with three equidistant projecting spokes is used to test the accuracy of the work. The handle of the gauge is twisted till a certain mark on it comes opposite a mark on a scale, which means that the spokes have had their length so adjusted that the gauge will only just slip into a correctly-bored cylinder, if held with the handle on the line of the axis of the cylinder. I tested one cylinder myself, and found it to be of the exact bore required.

The piston has a diameter $\frac{6}{2500}$ of an inch smaller than the bore, so that it may move in the cylinder with a minimum of friction. On the four piston-rings, which, being elastic, press tightly and constantly

against the walls, falls the task of preventing the passage of any gas from the cylinder head to the

FIG. 132.—Sand-blasting Gear Wheels. See page 333.

crank case during the compression and explosion strokes of the engine.

The valve ports and the ways for the valve stems are bored and threaded through a template or guide;

and a dozen more operations are performed on which we cannot dwell. Presently the cylinders, cranks, pistons, cases, flywheels, cams, piston-rods, valves, etc., reach the components fitting-room, where the work is divided among gangs which are always

Fig. 133.—Parts of Engines being assembled.

engaged on the same component, to enable each man to become a master at his own job.

When an engine has been put together, it is forwarded to the test shop, mounted on a bench, connected to a water-tank, and run "light"—that

is, without having to do any work—for ten hours continuously. It is then taken to pieces, carefully examined, and, if everything appears to be in proper condition, put together again and run under "full load" against a brake for two hours. The brake is a broad drum attached to the crankshaft, encircled by two turns of a thick rope, having one end permanently fixed and the other connected with a powerful spring balance. The engine is designed to run at a certain number of revolutions per minute (about 1,000) against the friction created by the rope being pulled with a certain tension; and from the speed and the tension is calculated the "brake horse-power." The drum is kept cool by a stream of water playing on its interior.

After being taken to pieces and examined a second time, the engine is assembled for the final test, made to measure the "torque" or turning power at all speeds from 150 to 1,000 revolutions per minute, and afterwards goes forward to the erecting-shop with the certainty that it will "pull well," and do all that is expected of it without further adjustment.

In the erecting-shop the engine meets the other parts of the *chassis*, or mechanical part of the car—the frame built of pressed-steel girders, the axles,

road wheels, change-speed gear, clutch, steering gear, radiator, tanks, etc. On the assembled *chassis* is put a rough "testing body," and the machinery is made to prove on the road its speed, flexibility, and hill-climbing powers. If it behaves

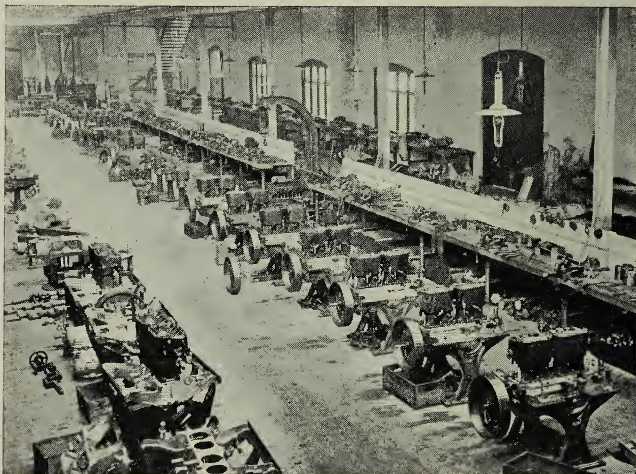


Fig. 134.—Engine-erecting Shop.

well, a coach-built body is substituted for the make-shift, and a second journey is made. Then the two main portions of the car are separated and sent to their respective painting-shops, where the gray "priming" is covered by from fifteen to twenty distinct coats of paint and varnish. Meanwhile all

the bright parts are plated and polished in an adjoining shop. Small articles of irregular outline undergo the ordinary electroplating process; but larger parts, such as change-speed levers, steering columns, etc., have sheet metal rolled on to their surfaces by a method very similar to that used in the manufacture of the old-fashioned and highly-prized "Sheffield plate," which permits a much thicker and more durable coating than could be applied conveniently in the plating-bath.

After the painting of the body comes the upholstering; and when the finished body has been attached to the painted chassis, the car is ready for the purchaser.

An interesting appliance used in this, as in a number of other factories of all kinds, is the automatic time-registering clock set near the entrance of each department. Every employee has a card, kept in a rack beside the clock. When he arrives in the morning he takes his card from its place, pushes it into a slot in front of the clock, and pulls a lever, which stamps the time on the card opposite the right day of the week. When he leaves the factory he does the same thing; and as such stamping is compulsory, and there is no arguing with a clock,

his goings-out and comings-in are known to those in authority, and he receives his just wages. The clocks are also used for recording on "job" cards the times of starting and finishing. On very nearly all classes of work the workman is able to earn a "bonus," or extra pay. A time is fixed for the job, say two hours. This is written on the card. At the commencement the workman stamps his card in a clock. Perhaps he is able to complete the job in one and a half hours. The card is stamped again, and the workman is credited with a bonus of half the wage he would have received for half an hour, the time saved. This amount is added to the fixed wage which he is paid by the day; so that an employee may earn, let us assume, ten shillings for ten hours' work, and two shillings extra for having got through his job in four hours less than the time allowed by the job cards. By this system the workman is encouraged to do his best, and the firm benefits by an increased rate of output and reduced cost of wage per piece.

Chapter XXI.

CYCLE-BUILDING.

Coventry a city of cycle factories—The parts of a cycle—How the parts are made—Shaping the cranks—An automatic lathe—Case-hardening—A machine for sorting out steel balls—Building the frame—Brazing—Sand-blasting—The effect of sand on metal and glass—Trueing the frame—Polishing the frame—Enamelling—"Lining"—Wheel-building—Making chain wheels—Electroplating—Polishing the nickel—Assembling the parts.

THE popularity of the cycle dates from the year 1885, when the late Mr. J. K. Starley introduced the low "safety." Since then the manufacture of cycles has developed into an important industry, employing millions of pounds of capital and many thousands of workmen. The chief centres of the industry in England are Coventry and, to a lesser degree, Birmingham. Here you will find many factories busily engaged on the construction of machines, which issue, sleek and shining, from them every year in vast numbers. The price of bicycles has been greatly reduced since the "boom" of 1896, when people paid anything up to £30

for a high-class machine. To-day fifteen guineas will buy an, in some respects, even better article, and the poor man may purchase a reliable mount for one-third of that sum. This cheapening is the result partly of competition, partly of improvement in the materials and machines used in the manufacture.

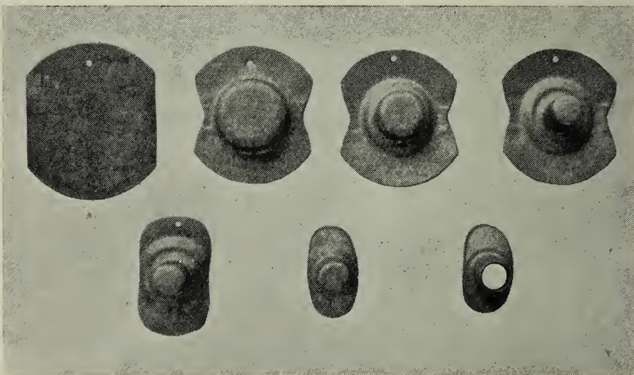


FIG. 135.—The various stages through which a steel plate passes when being shaped by a hydraulic press into a front-fork crown.
(Photo by Rudge-Whitworth Cycle Co.)

This chapter is intended to give you some idea of what goes on in a cycle factory, and I hope that it will be interesting reading to all cyclists who peruse this book.

A cycle is made up of the following metal parts:—
A *frame*, consisting of a number of steel tubes held together by steel sockets, or "lugs," to which they

are brazed; a *fork* for the front wheel—three tubes brazed to a "crown;" a *handle-bar* for steering; two *cranks;* two *pedals;* a *chain;* two *chain wheels;* two *road wheels,* each having a *hub* attached centrally to a rim by a number of steel *spokes;* five *spindles* for the wheels, cranks, and pedals to revolve on; *mud-guards; brakes; gear-case.*

HOW THE PARTS ARE MADE.

We will take the cranks first. Come with me into a smithy, where stands a row of powerful steam-hammers near an equal number of furnaces. A smith draws from a furnace a red-hot steel bar, and places it on a die fixed to the anvil of his hammer. The assistant jerks a lever up and down, and at each jerk the "tup," or head, descends with a mighty whack. In a few moments the end of the bar has been forced into the die, and has assumed the rough outline of a crank. This forging is sent to the machine-shop, and is bored for the spindle and cotter and pedal pins, and is threaded, along with a number of others, on to two steel bars, to form what is known as a "gallery" of cranks. The gallery is attached by the bars to a sliding bed, which passes it slowly under a revolving cutter shaped to the

longitudinal outline of half a crank. This whisks all the extra metal off one side. The gallery is then taken out, turned over, and passed under the cutter again. The sides being now finished, the face and back of each crank are planed true in other machines.

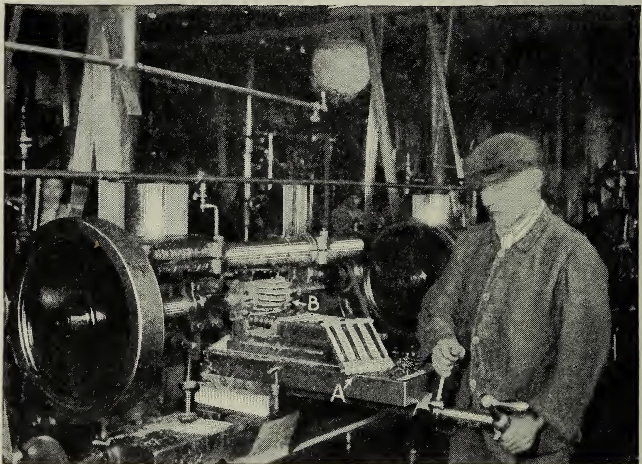


FIG. 136.—Shaping Cranks.—A, "gallery" of shaped cranks; B, revolving cutter. (*Photo by New Hudson Cycle Co.*)

Thanks to the introduction of this method, twenty cranks are now treated in about one-twentieth of the time formerly required to finish a single crank by hand; and it need hardly be said that the cranks are more perfect replicas of one another than they were under the old system.

Hubs and spindles are sometimes forged in the same way as cranks, and then turned up ; sometimes turned direct out of solid steel bars by automatic lathes.

The cups and cones for the bearings are invariably made in the second manner. It is quite an education to watch one of these lathes at work. A long bar is pushed into the jaws of a revolving chuck, through a central hole, and advanced towards a "turret," from which project a number of arms, each carrying a tool at the end. When a tool has finished its particular job, the turret revolves a certain distance and brings the next into place. Thus one tool bores out the inside of a cup ; another cuts a screw thread on the circumference ; a third separates the cup from the bar, and causes it to drop down a shoot. Then you hear a snick, and the bar has been moved out just sufficiently to give the tools material for another cup. In the course of the day hundreds of cups are made, the attendant having only to insert a fresh bar when needed. All cups, cones, spindles, and hubs are carefully measured, and if not dead true to gauge go to the scrap-heap.

The next thing to be done is to harden their surfaces, so that the balls which run on them may not wear them out of shape. At the same time this

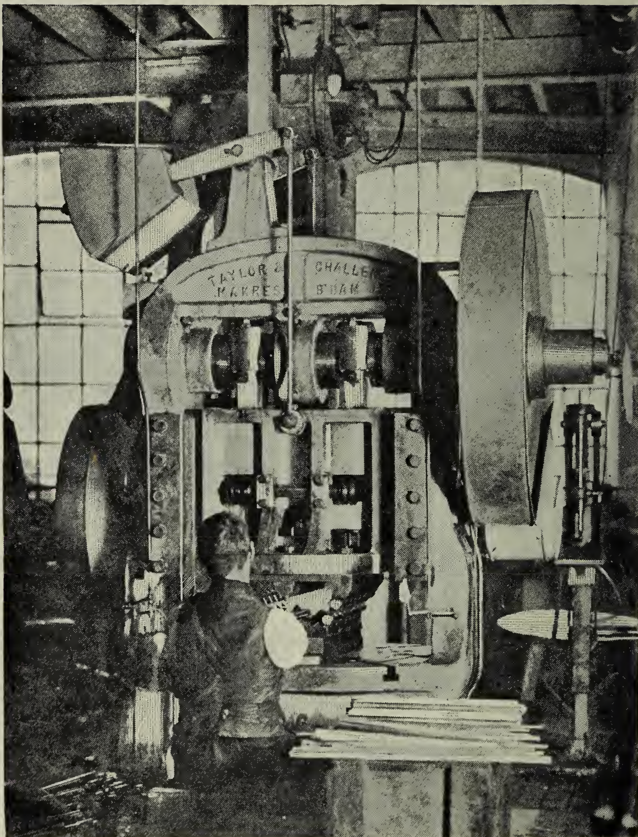


FIG. 137.—Press which shapes Chain-stay Tubes out of flat strips of steel.
(*Photo by Rudge-Whitworth Cycle Co.*)

hardening must not be more than superficial, or the part would become too brittle. So the parts are

packed in boxes in a carbon powder, placed in a furnace for a time until the skin of the metal has absorbed some of the carbon, and are cooled by being plunged in oil. They are then so hard on the outside that a file makes no impression on them. In Fig. 138 you see a crank spindle broken in half to show the soft, unhardened centre and the hardened outer skin.

Fig. 138.

The steel balls which contribute so largely to the easy running of the cycle are turned out of steel bars, and revolved for hours in a box with emery powder until they have been polished and ground into a spherical shape by the continuous friction. An automatic machine sorts them out by sizes, dropping each size into its proper compartment, and rejecting any one that is not a true sphere. A

well-tempered steel ball is so hard that you may hammer it into a plate of soft iron without doing it any harm.

THE FRAME.

The tubes for the frame are cut to their exact lengths by special machines; the lugs, bottom bracket,

FIG. 139.—Pinning the Frame together.
(Photo by New Hudson Cycle Co.)

and front-fork crown are lathed and cut to a standard size. When a frame has to be fitted together, the requisite lugs and tubes are assembled in a "jig" (Fig. 139), or holder, which grips them in their respective proper positions while the workman pins the tubes to the lugs ready for brazing.

In the brazing department of a factory there are a number of furnaces, each presided over by a smith. He takes a frame, or handle-bar, or front fork, as the case may be, and submits it to the flames until it is brightly red-hot. Powdered borax is then ladled on to the joints and allowed to run into every crevice, and afterwards fine brass filings, which melt and follow the borax, and, as the whole cools, weld lugs and tubes in a firm embrace which the roughest road will never loosen. Brazing requires considerable skill, since overheating of the tubes may burn and spoil them, while under-heating results in an imperfect weld.

Handle-bars after being brazed are filled with sand, heated to redness, and bent to shape over an iron "form." The sand prevents their collapsing at the curves.

The next process is that of

SAND-BLASTING,

to remove the borax, scale, and rough brass edges of a weld. The files which were formerly used have been replaced by a method of scouring the parts with very fine steel shot—technically termed "sand"—projected by compressed air from a nozzle. The

shot detach all roughnesses just as a coachman's hose washes dirt off a carriage wheel, and in a few moments the once rugged surface is bright and smooth. The sand-blasters work in chambers lined with steel plates, since bare brickwork or plaster would soon be eaten away by the flying shot glancing from the table. Even the steel plates are affected, for I noticed in one chamber that I entered how the steel on that part of the door which was protected by the jambs stood out quite $\frac{1}{16}$ of an inch from the exposed part. The workman has to wear a kind of helmet, with two glazed windows in front of him to see through. Compressed air enters the helmet at the back, and passes down round the head, enabling the user to breathe, and preventing the ingress of any dust or shot. After a few hours' use the window glasses are so etched by the shot that they have to be replaced. (See Fig. 132.)

The frames are next tested, and, if need be, straightened. The method employed by the Rudge-Whitworth Company is illustrated by Fig. 140. The "jig" consists of a massive bed-plate split down the middle like the bed of a lathe. Along the top runs a block D, with a deep mark scratched along its centre.

The frame is held at the bracket by two steel points, round which it can be revolved through the split. Attached to the jig is a flat steel gauge, hinging at one end to a point near the bracket pivots. The workman first raises this gauge, and if it does

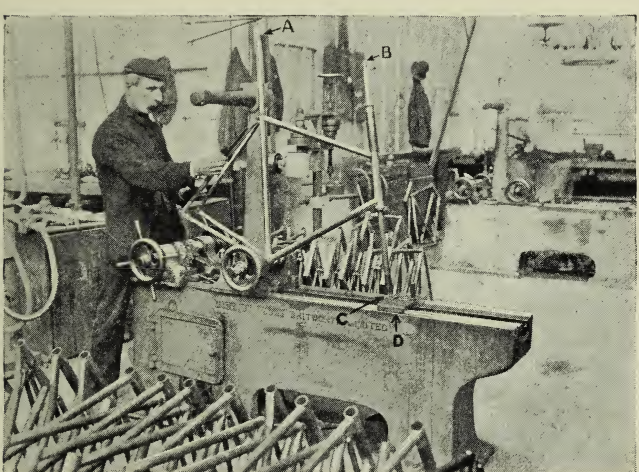


Fig. 140.—Testing the truth of Frames.
(Photo by Rudge-Whitworth Cycle Co.)

not pass centrally through the chain stays, he heats them with glass blow-flame and bends them true. Next he inserts a pointed steel bar A into the saddle lug, and another with a point at each end, B and C, through the head tube. The frame is revolved through the jig, and, if necessary, heated and bent

a little this way or that until every one of the three points is exactly in line with the mark on the sliding gauge D. In this manner perfect truth is obtained.

All the tubes of the frame and handle-bar have now to be ground bright by whirring emery wheels

FIG. 141.—Polishing Frames.
(Photo by New Hudson Cycle Co.)

in the polishing shop. Not a point on the exterior escapes, as the workman twists and turns the parts about, allowing the wheels to remove the merest skin of metal. The speed of the wheels is such that sparks fly off in a fiery shower, which in the dark would be quite a fine pyrotechnic display. Along

with the sparks are millions of atoms of emery and metal, that might be injurious to health if inhaled; so that you will find below every wheel an opening connected by big tubes with a large chamber outside the factory, from which the air is being constantly sucked by an electrically-driven fan. The draught is sufficient to catch and whirl away all noxious matter as it falls.

Now watch what happens to the polished frames. They are dipped in paraffin or turpentine, and hung in a large oven heated by water, which "sweats" all grease out of the pores of the metal. This done, the workman must be careful not to touch the metal with his bare hands. Here are several large troughs full of intensely black, shining enamel. Into one of these a dexterous employee dips the frame bodily. As soon as the surplus has drained off, he places the frame in a second oven, where it is subjected for three hours to a temperature of 350° F. It is thus dipped and "stoved" three or four times, being rubbed down with fine pumice-stone after every stoving but the last. The heat causes the enamel to melt and distribute itself quite evenly over the frame —which has its position altered several times during a stoving—and then to set hard. It is impossible

to get so good or durable a surface by merely painting the frame with an air-drying enamel.

The final touches are given by very skilled workmen, who "line" the enamel in colours or gold. A "liner" trusts entirely to his eye when applying the colours. He takes his brush, dips it in the paint, and, resting one finger on the frame to guide him, draws line after line of constant breadth with marvellous quickness and accuracy.

The application of gold is a more tedious process. The liner paints the surface over with isinglass, sticks gold-leaf on it, draws lines of black enamel where the gold lines are to be, washes off the gold not covered by the enamel, and then the enamel itself, exposing the golden lines beneath.

WHEEL-BUILDING.

The making of a rim is a very interesting process, performed by a machine having many pairs of rollers, through which a ribbon of steel is drawn. The rollers gradually bend the strip into the section of a rim, with a deep channel in the middle for the spoke ends. On leaving the last pair, the strip enters a kind of cage, and is bent by it into a circular shape. The moment the circle is complete, a cutter severs

the rim from the strip. A plate is riveted to the ends to hold them firmly together, and the rim is placed in a jig (Fig. 142) for the spoke holes to be drilled in it, accurate spacing being effected by a

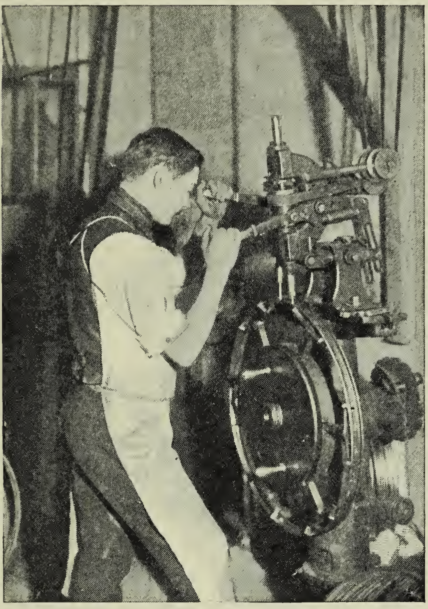


Fig. 142.—Drilling Spoke Holes in a Rim.
(Photo by New Hudson Cycle Co.)

ratchet acting on a plate notched round the circumference, so that the rim is moved the correct distance between every two descents of the drills.

The spokes screw into little brass nipples with

heads just large enough to prevent their passing through the rim holes. The threads were formerly made on the spoke ends by passing them through dies. In the modern factory threading is effected by rolling the spokes between jaws grooved longitudinally, which *squeeze* the thread on the wire in a fraction of a second.

The wheel-builder laces a few spokes through the flanges of the hub, attaches them to the rim by nipples, and tightens them up until the hub is approximately in the centre. The remaining spokes are then placed in position, and the roughly-adjusted wheel is mounted on its spindle and set in a jig to be trued. This operation occupies but a few minutes.

The larger chain wheel of a cycle is fashioned out of a circular "blank" stamped from a steel plate. The blank is pierced at the centre, mounted on a spindle, and revolved against a grooved roller, which raises a ridge on each side about $\frac{3}{8}$ of an inch from the circumference. This is for the chain to lie on. The spare metal is then stamped out by a very powerful press, in such a way that only a few spokes are left to connect the rim to the centre. The wheels are toothed in batches, like watch wheels, by automatic milling machines.

ELECTROPLATING.

It is customary to plate many parts of a cycle with nickel, to protect them against rust and give them a smart appearance. They are prepared for nickelling by being well polished and dipped in a solution of caustic soda, which removes all grease and dirt. As nickel does not adhere to steel very readily, it is advisable that a film of copper should precede the nickel. So most plating departments contain two sets of plating tanks, one filled with copper, the other with nickel solution. Copper rods laid across the tanks are connected to the negative pole of a dynamo, and plates of copper or nickel (suspended in the tanks) to the positive pole. To deposit the copper you merely have to tie a piece of copper wire round a part and hang it in a coppering tank from one of the negative rods.

After a minute or two the bright steel is covered with a beautiful pink film, and is ready for transference to the nickel bath. To hasten the deposition of nickel, either the solution or the object to be plated is kept in motion. One method often adopted is to circulate the liquid by means of a pump; another (used at the New Hudson Cycle Company's

factory) is to attach the parts to chains travelling above the tank (Fig. 143).

When it leaves the bath the nickel deposit is of a dull white, unpleasing to the eye. We will therefore return to the polishing department, and see how the brilliant sheen which we associate with nickel-plating

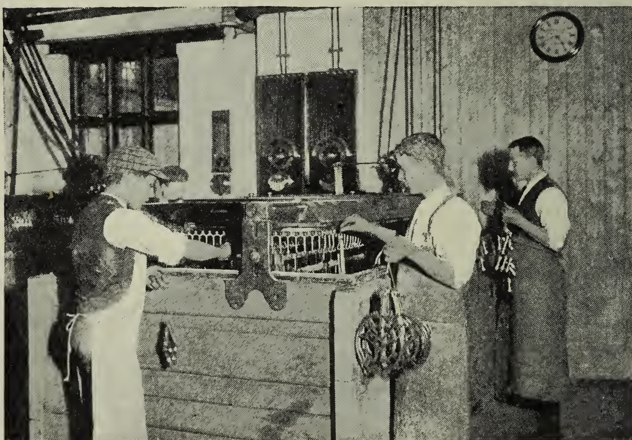


FIG. 143.—An Electroplating Outfit.
(*Photo by New Hudson Cycle Co.*)

is produced. The workman holds the parts against a "mop" made of many dozens of calico discs riveted together, which, when revolved at a high speed, become stiff with the centrifugal force, though their edges are soft enough not to scratch the nickel. Crocus powder is the polishing agent used.

ASSEMBLING THE CYCLE.

Finished cycle parts of all kinds come together in the storerooms. When a cycle of any particular size or shape is ordered, one of the men in charge of the store collects into a box a complete set of parts—frame, fork, handle-bar, cranks, pedals, wheels, chain, chain wheels, balls, mud-guards, brakes, etc.—and hands them out through a hatch to an "assembler," who builds them into a machine as fast as he can, for he is paid so much per machine.

The assembling, as I have seen it done, proceeds in the following order:—The bottom bracket spindle and bearings adjusted; cranks affixed to spindle; chain wheel mounted on spindle; back wheel mounted; back mud-guard fitted; chain mounted and adjusted; gear-case fitted; saddle placed on pin; front wheel mounted in fork; mud-guard attached; bearings of the steering head adjusted; handle-bar fitted; brakes attached. This may take from half an hour to two hours, according to the ease with which the parts go together. The assembled cycle is handed over to an examiner, who scrutinizes it closely, feeling all the tubes for inequalities, spinning the wheels, testing the bearings and brakes, and generally does

his best to discover any imperfections. If successful, he writes particulars on a label, and sends the machine with this hung round it back to the assembler, who has to put things right. But should the machine prove satisfactory, full details of it are entered in a large ledger, and it goes "into store" to await the time when it shall commence its travels on the road.

Chapter XXII.

THE CRADLE OF A LOCOMOTIVE.

The big railway works of England—The Swindon works—Some ot the sights to be seen there—Monster locomotives—The parts of a locomotive—Casting the cylinders—Boring and finishing the cylinders—Shaping the frames—Crank axles—Turning up the driving-wheels and shrinking on the tyres—The boiler—Its parts—Pressing plates into shape—Drilling bolt and tube holes—Riveting boiler plates—Inserting the tubes—Testing a boiler—Erecting a locomotive—Feats of erection—Testing the locomotive on the rails and on a special registering machine.

IN the United States it is customary for a railway company to order its rolling stock—locomotives, trucks, and passenger cars—from manufacturers who make a specialty of such things, merely indicating by means of diagrams and descriptions the exact character, shape, and size of the thing required. But on this side of the Atlantic the big companies have each their own locomotive and carriage works, completely equipped in every detail. At Swindon is made all the Great Western Railway rolling-stock ; at Crewe, the London and North-Western ; at Derby, the Mid-

land; at Doncaster, the Great Northern; at Newcastle, the North-Eastern; at Stratford, the Great Eastern; at Nine Elms, the London and South-Western; at Ashford, the South-Eastern; at Horwich, the Lancashire and Yorkshire, etc. Round each works has grown up a town peopled by the employees and their families. Swindon is one of the most remarkable instances of increase in a railroad town. Fifty years ago it had about 2,500 inhabitants; to-day it has 45,000, of whom some 15,000 are employed in the works.

By the courtesy of the engineer-in-chief of the Great Western Railway, I was allowed to spend a day among the many acres of engineering shops which constitute the Swindon Works. It is a long walk from one end of the sheds to the other. A stranger dropped suddenly among the buildings might well imagine many of them to be independent factories, so varied are the operations conducted in them. Peep into one, and you will see a large sawmill cutting up wood to be built into trucks and carriages. Another is given over to steam-hammers. As you watch, a furnace is opened, and a man rakes out a cubic foot of white-hot steel on to a low trolley, which is drawn off to a large hammer. Two smiths,

wearing wire masks and sheet-iron boots and leggings to protect them from the terrific heat, toss the ingot on to the anvil and turn it about while the hammer kneads it like so much dough into this shape or that.

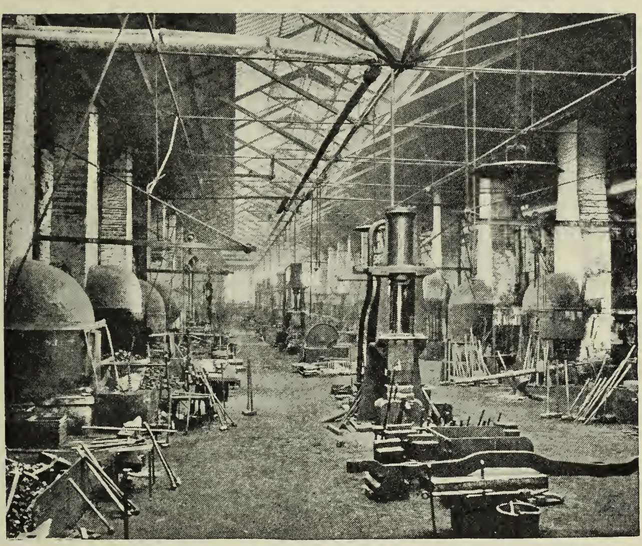


FIG. 144.—In the Smiths' Shop, Swindon Works. Steam-hammers down the centre.

The sparks fly out in a way that makes the unaccustomed onlooker retreat to a safe distance to save his clothes. Elsewhere the shaped ingot is heated again and fed into a rolling-machine, driven by an engine having two enormous flywheels 22 feet in

diameter. It passes to and fro five times, being squeezed and flattened out each journey, till, instead of the short, stubby mass, we see a long bar, some $1\frac{1}{2}$ inches thick, which a steam-shears cuts up with the greatest ease into several portions.

Passing on, we come to a department where laminated axle springs are made out of thick sheet steel. The leaves are cut to shape, bent to a curve, built up, and tested in a machine that suggests an enormous steelyard. And then we reach a drop-forging shop, and the bolt shop—the birthplace of innumerable stays, bolts, and nuts; and pass to a large building where sheet-brass is being beaten into covers for steam domes and safety-valves, and men bend thick copper pipe after filling it with resin.

But I must not attempt to give you a glimpse of all the things to be seen during my tour, or the chapter will become over-long. The locomotive is the king of the works, and on it our attention shall be centred in the following pages, which describe in outline the main processes of construction. New types of locomotive are being evolved constantly, each more powerful than its predecessor; for the engine designer must always be on the lookout for possible improvements, so as to get better results

from a given weight of fuel. Some of the latest G.W.R. expresses are monsters—how big, one can only realize by standing on the rail beside them. The eyes of a six-foot man are about level with the bed-plate, and above this tower the boiler and its appurtenances. If such a locomotive were dumped down on a country road and confronted by an ordinary traction engine, the latter would look like a pug dog facing a mastiff.

A locomotive consists of many thousands of parts, which may be grouped under the following heads:—The cylinders, pistons, connecting-rods, eccentrics, and valves, which convert the steam energy into motion; the frames, which carry the boilers, cylinders, and running gear; the boiler and smoke-box; the wheels, axles, and cranks; the tender.

Any one who is unacquainted with the general principles of a steam-engine and with the main features of a locomotive boiler is recommended to consult the opening chapters of "How It Works," paying special attention to Fig. 6 on page 20.

THE CYLINDERS.

and their attachments form the largest *castings* incorporated into a locomotive. We will therefore

FIG. 145.—The Foundry at Swindon Works. On the right is seen a cylinder casting suspended by a travelling crane.

adjourn to the foundry to see the first stage in their manufacture. The building has a spacious floor, on which men are ramming sand busily into hundreds of iron boxes. A large proportion of these are the moulds for the "chairs" spiked to the sleepers for the rails to rest in. But these boxes are mere pigmies in comparison with the large coffers devoted to casting the cylinders which the huge G.W.R. express engines now carry. The preparation of a cylinder mould takes a long time, on account of its irregular outline and the necessity for leaving ports, or holes, in the metal for the steam to pass through from the steam-chest to each end of the cylinder; to say nothing of the fixing of the "cores" in the positions occupied by the bore of the cylinder and piston valves. When the top half of the mould has been placed in position over the lower half and securely bolted down, molten steel is poured from a mighty ladle into the mould through a hole left for the purpose, and the metal is allowed to cool for two or three days. The top of the mould is then removed and the casting dug out of its surrounding sand, the ports are cleared, and all metal that has spread through the joints of the mould is chipped off by pneumatic chisels.

The next stage takes us to the machine-shop. The first thing to be done with the casting is to bore out the cylinder, since from the axis of the bore all measurements are made. So the mass is lowered by an overhead crane on to the bed of a big lathe, and adjusted in line with a boring tool having three cutters projecting from it like so many spokes. As these revolve inside the bore they move slowly forward, scraping large shavings off the walls of the cylinder from one end to the other. Two cuts are given—the "rough" and the "finishing." The steam-chests are bored if piston-valves are used; or if slide-valves, the faces over which these work are planed flat.

Next, holes are made for the bolts which hold on the cylinder covers and steam chest by machines which drill the holes and tap a screw thread in them as well as through a template.

The covers and piston are castings, turned up in lathes; all the rods are formed out of large steel bars.

THE FRAMES.

The wheels support the frames, and the frames in turn carry the cylinders, boiler, etc., so they have to be very stoutly built. The frame plates arrive

from the steel mills as steel sheets about 30 feet long, 4 feet wide, and $1\frac{1}{8}$ inches thick. On these the outline of a frame is chalked from a pattern. Then each plate is placed on a great table and passed under a very powerful punch, which stamps out contiguous circles of steel all along the outside of the lines. The "waste" having been removed, the plate is heated in a furnace, annealed, or softened, and rolled quite flat.

It would cause a loss of time to machine the edges of each plate separately. Eight or ten plates, according to their thickness, are stacked on the top of one another, clamped together, and introduced to a large slotting machine. The bed of this can be moved backwards and forwards, and the tool sideways, so that any point on the edge is accessible to the tool. The plates are similarly grouped to be drilled with holes for fastening on the cylinders, cross plates, etc.; and when the drilling is finished, they are ready for the erecting-shop.

CRANK AXLES.

If the engine has cylinders inside the frame under the smoke-box, the cranks must be included in the driving-wheel axles. The cranks and axle are in

some cases lathed out of a large forging in much the same way as motor-car cranks (see page 315); or, and this is the method now preferred at Swindon, are built up out of large slabs for the crank webs (Fig. 146), and rolled bars for the shaft and crank pins. The slabs are first planed on both sides to an exact gauge thickness, and then placed on a table under a tool which eats a circular groove right through one end, and liberates a "cheese," or short

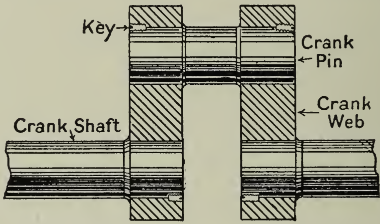


FIG. 146.—Showing how a Crank is built up.

cylinder, of metal. The table is turned round, and another cheese is cut out of the other end, at a certain distance from the first. The holes of the web have now to be cleared out by a borer to gauge size, a trifle less in diameter than the ends of the pieces of turned shaft which act as crank pins and axle. The webs are then expanded by heat, and the cold shafts and pins are slipped into place, and nipped by the web as it contracts in

cooling. Steel keys are screwed in at the joints to prevent any part moving on another; and the now complete crank shaft is put in a monster lathe, to

Fig. 147.—The Crank-shop at Swindon Works.

have the pins and other rubbing surfaces turned to gauge dimensions.

WHEELS.

Outrigged, or outside-cylinder, engines have the cranks cast on the driving-wheel bosses. They are bored for the crank pins in a manner that calls

for no special notice. But the process of mounting and tyring engine-wheels of all types is interesting. The wheel centre, which includes the hub, or boss, is so drilled in a lathe as to make a tight fit for the axle, on to which it is forced by a powerful hydraulic press. A slot has already been cut in both axle and wheel for a steel wedge key, which is now inserted. The axle and its two wheels are then mounted in a double-ended lathe, which turns the rims of both wheels simultaneously to a certain diameter. Meanwhile in another place the rolled-steel tyres have been lathed internally to a diameter rather less than that of the rims.

A tyre is lowered by a crane into a circular pit, from the wall of which project a dozen large bunsen gas burners. These play on the metal for about a quarter of an hour and make it almost red-hot. Then the crane seizes the tyre and transfers it to a circular iron plate, resting on a solid bed, and lowers into it a wheel centre, which, now that the tyre has been expanded by the heat, enters quite easily. As it cools, the tyre grips the rim with tremendous pressure; but to make assurance doubly sure, a circle of flat steel is driven into a deep groove in the inner face of the tyre (see Fig. 148). This

groove widens inwards, so the steel guard is practically keyed into it. A flange on the inner side of the tyre prevents the rim working off in the other direction. To remove the tyre, the edge has to be machined away sufficiently to release the guard. The wheel is then heated in the gas pit, and the tyre is knocked off with sledge-hammers over the table.

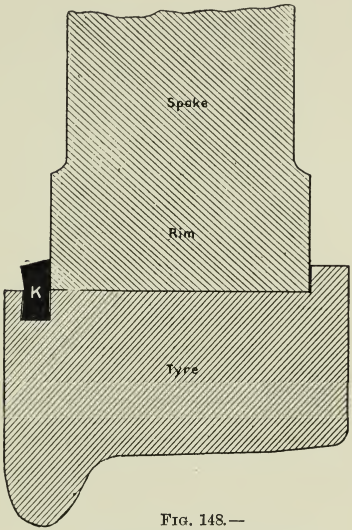


FIG. 148.—
Section of Spoke, Rim, Wheel, and Key (K).

It only remains to true the exterior of the tyres to gauge to complete the pair of wheels.

THE BOILER.

Vulcan himself would have been astonished by the din in the boiler-shop. His workshop on Mount Etna did not include pneumatic tools, and until you have heard a dozen or more mechanical air-driven riveters and caulkers at work on a boiler shell

FIG. 149.—Scene in a Boiler-shop.

simultaneously you don't know what real noise is. Though I put my hand to my mouth and bellowed into my guide's ear, I quite failed to "keep in communication" with him; and my throat growing sore with the exercise, I soon abandoned all attempts at conversation.

The boiler is the most imposing and, in many ways—to the layman at least—most interesting part of a locomotive.

It consists of the following parts: the barrel, the fire-box casing, the fire-box, and the tube plate for the smoke-box end. With the exception of the third, which is copper, these are made of mild steel plate, $\frac{5}{8}$-inch to $\frac{3}{4}$-inch thick. The barrel plates, two in number, are levelled to remove any buckles, and then passed through a rolling-mill, having three rollers adjusted to bend the plate into a circle. Where the barrel is of a type that expands towards the fire-box end, the rolling is a rather difficult business.

The front plate of the fire-box casing, which engages the rear end of the barrel, is called the "throat" plate. Near the top a large hole is cut for the barrel. The edges of the hole and the plate are turned over or flanged by heating the plate and

squeezing it between the dies of a hydraulic press capable of exerting a pressure of 600 tons. The flanges are cut to the right size by a band saw running over two large driving pulleys.

The tube plate is flanged in the same manner; but the copper plates have to be flanged by striking with wooden mallets over iron forms, as the metal would tear in a press.

After shaping comes the drilling of many hundreds of rivet, bolt, and tube holes. The tube plate and front fire-box plate require piercing some two hundred times each with a 2-inch drill, for the tubes. The fire-box and its casing, which are separated by a few inches to permit the circulation of water, are held together by scores of copper stays; so they too are dotted over closely with holes. Finally, there are the rivet holes at every joint in the plates. The boring is done by drills mounted on the end of long arms, the object being placed on cradles that can be inclined in any direction so as to offer the surfaces to the drills at the proper angle. Rivets that can be got at conveniently are closed by hydraulic riveters, which do their work very quickly, and at the same time press the plates tightly together, so that a good joint is made.

As soon as the barrel rings have been riveted to one another and the rear one to the fire-box shell, the fire-box is inserted and riveted to the foundation

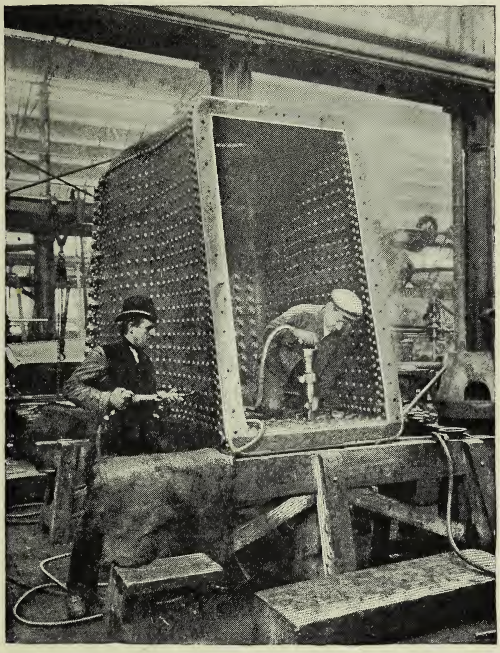


FIG. 150.—Closing the Stays of a Fire-box with pneumatic tools.

ring, which prevents water from escaping at the bottom of the water-jacket. Men armed with pneumatic holders make threads in the holes bored for the jacket stays, driving a tap through both steel and

copper casings. When the tap has worked its way right through the latter, another man inside the fire-box pulls the tap out of the holder and hands it back to his mate, who repeats the operation in another hole. Other men expand the projecting ends of the stays with pneumatic riveters, while others are busy closing all seams by battering them with pneumatic "caulkers." These last make a terrible noise.

If you look closely at the fire-box stays you notice that each has a hole about $\frac{1}{8}$ of an inch in diameter drilled down its axis. This hole extends from the outer end almost to the other. If the stay breaks, the fact is at once made known by water and steam issuing from the hole. Unless there was some such tell-tale, a number of stays might be fractured and the boiler be dangerously weakened without any one being aware of it.

Now for the many steel fire-tubes. In the largest boilers these measure upwards of 23 feet in length. Each tube is inserted from the fire-box end, and expanded into the tube plates at both ends by means of a tool having three small rollers that press on the inside of the tube as it rotates.

The top, or "crown," of the fire-box has meanwhile

been stayed to the top of the boiler by a large number of steel bolts about 18 inches long; and the boiler is ready for the fitting of safety-valves, injector, gauges, regulator box, etc. When these are in place, the boiler-makers test it by filling it quite full with water and lighting a small fire in the furnace to expand the water. The latest pattern boilers work at about 220 lbs. pressure to the square inch. They are tested to from four to seven times this pressure; and as they generally stand even this, there is little likelihood of their giving way under ordinary working conditions. The second test is made with steam for six hours; and then the boiler goes to the erecting-shop.

ERECTING

begins with the frame. The side plates are placed on low trestles, and the sockets in which the axle-boxes move up and down are riveted to the plates, and all necessary holes for attachments are drilled. The workmen then stand the plates on edge, and set them parallel and in line with one another, in readiness for the cylinders, which are lowered into position at the front end, and adjusted by passing fine cords through their centres and measuring the

distance between them and the frame plates. When the correct position is attained, bolt holes are drilled and the cylinders fixed.

The boiler and smoke-box are now lowered into their places; the fire-box passing down between

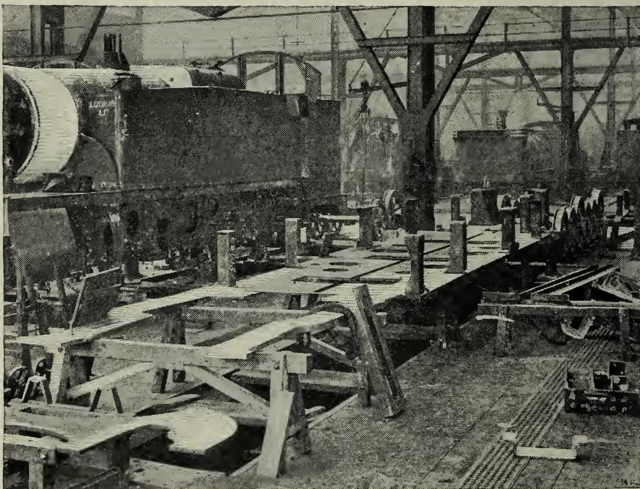


Fig. 151.—In the Erecting-shop. Getting the side plates in position.

the plates until brackets attached to its sides meet the plates, and the smoke-box settles into the curved bed in the upper surface of the cylinder castings, to which it is fastened. The barrel of the boiler is only supported by the smoke-box, not attached to

it, so as to be able to move in and out a little as it expands or contracts at different temperatures.

While the cross plates for the piston and valve rods to work through are being placed, a gang of jacketers "lag" the boiler with a thick coating of

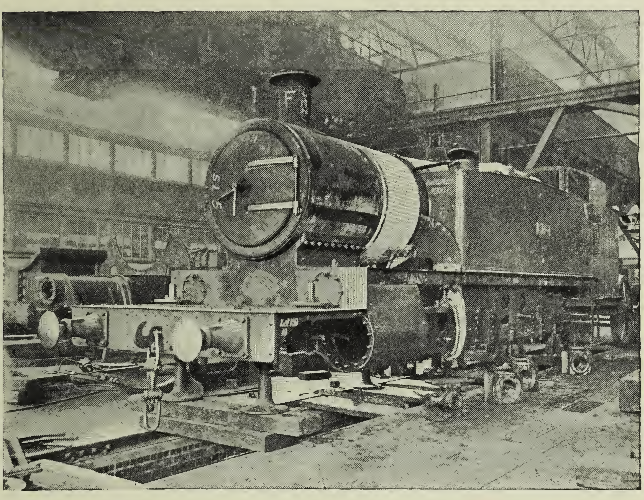


Fig. 152.—In the Erecting-shop. The boiler, cylinders, and tanks in position.

magnesia and asbetos, and cover this with thin steel plate. But for this non-conducting jacket, it would be difficult to keep up a good head of steam even on a warm day, and impossible on a cold one.

The fitting of the cab, tanks, pistons, and running

gear follows; and then a great crane lifts the engine bodily while the wheels are moved forward under their axle-boxes, and lowers it again. The valve-setters next get their innings; and also the painters, who put on a priming coat, and then three coats of green or black, the latter below the bed-plate. Lining and varnishing constitute the final touches.

We have, of course, omitted many details of erection, and for the very good reason that, if they had all been included, this chapter would have occupied a large part of the book.

It usually takes several weeks to put an engine together. But by increasing the number of men employed on the job, and having everything in order beforehand, the time can be greatly reduced. As examples of fast work, I may mention the erection of a London and North-Western goods engine in twenty-five hours and a half; and that of a similar Great Eastern engine and its tender at the Stratford shops in less than ten hours. In both cases the engine ran its trial trip immediately after completion.

Our own engine is ready to do the same. It is weighed, and got under steam for a short run to test the gear. Any needful adjustments having been

made, it goes for a longer trip, and if everything seems right, is handed over to the traffic staff, who put it first to goods and then to passenger work—if it is of the passenger type. Plenty of locomotives travel more than a million miles before their work is done—one at least has double this distance to its credit. But it is possible that the splendid engines now being built may be obsolete long before they are worn out, since electricity is fast ousting steam for suburban traffic, and presently may be harnessed to our long-distance expresses. When that day arrives, we shall be freed from a certain amount of smoke and dirt; but with the monster steam locomotive, the embodiment of power and motion, will depart the most imposing sight to be seen on the railroad.

In the repairing shop, which has accommodation for one hundred locomotives, is a very interesting apparatus used to test an engine in various ways. The engine is run on to a platform and lowered until its driving-wheels rest on an equal number of wheels revolving in a frame below. The wheels are connected to a brake drum, and also to a wheel which works a couple of large pumps. At one end of the platform stands a dynamometer, or pull-

measurer; not far from it are a revolution counter and speed recorder; and above it are tanks of water.

In order to test the pulling power of the locomotive the couplings are hitched to the dynamometer and the resistance of the brake drum is increased. The driving-wheels, in order to revolve those they rest on, have now to do some work, and tend to move the engine off the wheels, with a force that is recorded by the dynamometer. By tightening up the brake the pull on the couplings may be increased until the engine slips its wheels, which means that it has exceeded its limit of tractive power.

Then, again, the engine is run against a certain resistance on the brake for a given time, for the work done to be compared with the amount of fuel consumed and water evaporated. Or if it is desired merely to let the "motion"—pistons, valves, guides, etc.—get down to their work, the brake is taken off and the pumps coupled up, so that the energy expended may not be wasted. I much regret that at the time of my visit no engine was being tested, as the spectacle of the driving-wheels whirling round at very high speeds without "locomotiving" is one that may be seen only occasionally for a second at a time in a station.

Chapter XXIII.

PENS.

How a Roman wrote his letters—Origin of the word *pen*—Quill pens—Birmingham and the steel pen—Interesting pens—The making of a pen—Sheet steel—Cutting out the blanks—Marking the maker's name—Piercing—Raising—Hardening and tempering—Scouring—Grinding—Slitting—Potting—Testing.

WHEN a Roman gentleman wished to send a letter, he took a couple of small, thin wooden boards smeared on one side with wax, and scratched his sentences on the surface of the wax with a stylus, or pointed instrument of metal or stone, placed the two waxen surfaces together, bound the tablets with a silken thread, and sealed its ends. For literary purposes he used a sharpened and split reed, very similar to that used by some Eastern races to-day, and ink. The reed was superseded in Europe early in the Christian era by the quill, a feather from the wing of some large bird—that of the goose, swan, or crow being generally preferred. From the Latin word *penna*, which means a quill feather, we

have our term "pen," with which may be compared the French *plume* (Latin, *pluma*) and the German *Feder* (a feather). And it is owing to its utility for sharpening a quill that the small pocket-knife is known as a penknife, though now we seldom use it for such a purpose. Quills are prepared by heating them in sand and scraping off the soft outer skins. As they cool they become suitably hard and elastic. Nearly a century ago Joseph Bramah, the inventor of the hydraulic press, invented and patented a machine for stamping nibs, or separate writing points, out of quills; and so prepared the way for the steel pen, which appeared soon afterwards, though it did not come into general use until about the middle of the nineteenth century. Simple as it appears, the modern metal pen is the result of much experiment, and has taken several decades to arrive at its present excellence and cheapness. Its construction includes many separate processes, some employing very delicate and ingenious machinery, as we shall see in subsequent pages.

Birmingham is the chief world-centre of the pen-making industry. It contains thirteen out of the twenty-five factories which supply civilization with these useful little articles; the rest being in France,

Germany, and the United States. Every week some 22 tons of steel are converted by the Birmingham manufactories into about 28,800,000 pens.

I have to thank Messrs. William Mitchell, Limited, of the Washington Works, Cumberland Street, Birmingham, for some exceedingly interesting hours that I spent among their workpeople gathering information for this chapter. As a preliminary, I was shown a number of specimen cards, which displayed, among many scores of different varieties, some very curious pens adapted for special purposes: the sickle-shaped, for Swedish back-hand writing; the double-pointed, for ornamental work; the rough-tipped, for scraping up the surface of parchment to allow the ink to penetrate; the lithographic, $\frac{3}{1000}$ of an inch thick, and as lissom as a piece of paper, to make downstrokes only; the stiff duplicating pen; a tiny pen only $\frac{1}{4}$-inch long and $\frac{1}{16}$-inch wide.

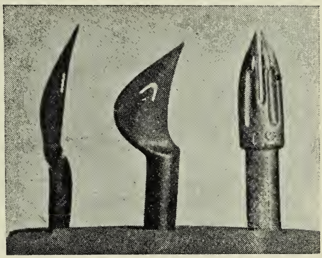


FIG. 153.—Some curious Pens. That in the centre is for back-hand writing, that on the left for making double lines.

The processes of manufacture are practically the same for all pens, so my task of enumerating

them is simple. Let us start at the beginning—namely,

THE RAW MATERIAL,

which arrives from Sheffield as sheets of crucible steel 6 feet long and 18 inches wide. These sheets are cut transversely into strips, and the strips are put into iron boxes and placed in a "muffle," a kind of oven, where they remain until the boxes are a cherry red heat. Then they are withdrawn, and by being allowed to cool slowly become annealed, or soft, and easily worked. After a cleaning in sulphuric acid and water they go to the rolling-mills to be reduced to the thickness required—which in the case of the well-known "J" pen is $\frac{7}{1000}$ of an inch. The rolling not only lengthens and thins the strips, but toughens them as well, as the elongation is across the grain of the original sheets from which they were cut, and so subsequently the metal does not tend to break in any particular direction. The man in charge of the mill has a very delicate micrometer gauge and a number of plates of the standard

Fig. 154.—A large and a very small Pen compared. Between them is a shilling. The smaller pen is only $\frac{1}{16}$-inch wide.

thicknesses of the pens whose names are respectively stamped on them. If "G" pens be the order of the day, he takes the "G" plate and sets the jaws of the gauge by it, and keeps rolling the strips until they just pass into the gauge. After this operation the steel is bright and fairly hard.

CUTTING THE BLANK

is the first mechanical operation in the manufacture of a pen. The machine used has a large vertical screw, which, when a handle attached to the top is partly revolved, presses a punch down into a "bed" containing a hole of the same shape as, but very slightly smaller than, the punch. The workmen who make the punches and beds are highly skilled, and only after many years of practice do they attain perfection.

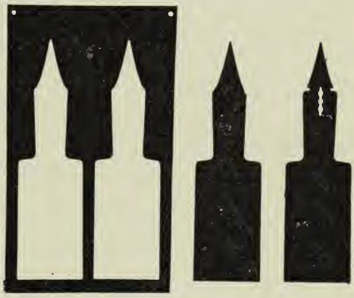


Fig. 155.—Plate from which the "barrel" pens seen on the right have been cut.

The operative takes a strip in her left hand, and introducing it at the back of the machine, pushes it gradually towards her, stamping out blank after

blank by pulling the heavy screw handle. Each blank falls through the bed into a receptacle below.

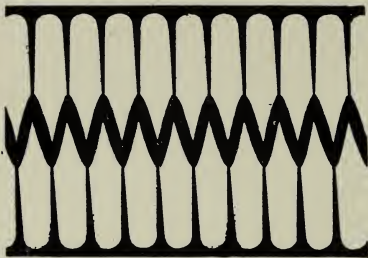


FIG. 156.—Steel strip from which a number of pen-blanks have been cut.

When one side of the strip is finished, the other is treated similarly; and, as you will see from the illustration of a part of a stamped strip, the points of one row of blanks alternate with the points of the other row to economize material.

On one edge of the blank a little nick is made, so that during other operations the same side may be kept uppermost.

MARKING THE NAME

follows. The required wording and design are cut upon a steel punch fixed to the bottom of a heavy weight moving up and down in a frame after the manner of a pile-driver. A rope attached to the upper end passes over a pulley and down to the operative's foot. She holds a handful of blanks in her left hand, and with her right places them one by one between guides on the bed of the

stamp, raising and releasing the weight with her foot to give the necessary impression to each. The stamped blank is flicked from the bed by so quick a motion of the right hand that the eye can hardly follow it.

PIERCING.

The blank is now punched with a central hole for holding the ink, and in some cases (the "G" pen, for instance) has parts removed at the base of the point to increase the elasticity (Fig. 157). This operation resembles the cutting of the blank from the strip. The tools (punch and bed) used are extremely delicate.

FIG. 157.—On the left a "blank;" on the right the same after being pierced.

The rolling and marking have hardened the steel again, and the blanks must therefore go into the annealing furnaces once more before they can be curved, or "raised," to the proper shape for the penholder.

RAISING

is performed in a screw press. The soft blank is laid on a curved die between guides, and forced into it by a punch. If any letter has to be embossed on the pen, it is done before raising, in a special press.

HARDENING AND TEMPERING.

You might think that if the pen were now slit it would be complete. But you could not use such a pen. Directly you began to press on the paper the points would turn up and open, and remain open, being soft and inelastic. A duly finished pen must be tough and springy, that it may open and close a million times without losing its shape. So after raising, the pens are placed in closed pans and heated for a short time in a furnace from which all air is excluded. The attendant draws out the pans when red-hot, and empties them into a tank of whale oil. This cools the pens at once, making them hard, but so brittle that they require tempering. Accordingly they are boiled in strong soda water, which frees them from all grease, and put in iron cylinders revolved by hand over a gas or charcoal fire, until they turn a light-blue colour. A boy keeps testing them

by picking one out and crushing it in a pair of tweezers. As soon as the proper pitch is reached, all the pens are flung into a pan to cool. This process gives them the necessary elasticity.

SCOURING.

At this stage they are covered with an unsightly black scale, and are rough at the points. The next step therefore is to clean them in a bath of diluted acid, called "pickle." After this they are washed with clean water and rotated in drums containing water, lime, sawdust, and pebble, which knocks off all the scale, smooths the points, and produces a gray surface. A further scouring with dry material in other drums polishes the pens to a silvery brightness.

The drums are of various shapes, and differently mounted. Some revolve evenly on their axes, others turn head over heels like a barrel churn, others, again, are mounted obliquely, according to the kind of pen which they are designed to treat. Mr. W. J. Mitchell, my guide, explained that it had been a troublesome business to discover how to scour some kinds, and that in one case he was obliged to lie flat on the floor and watch through a window in the drum the manner in which the pens rolled over one another.

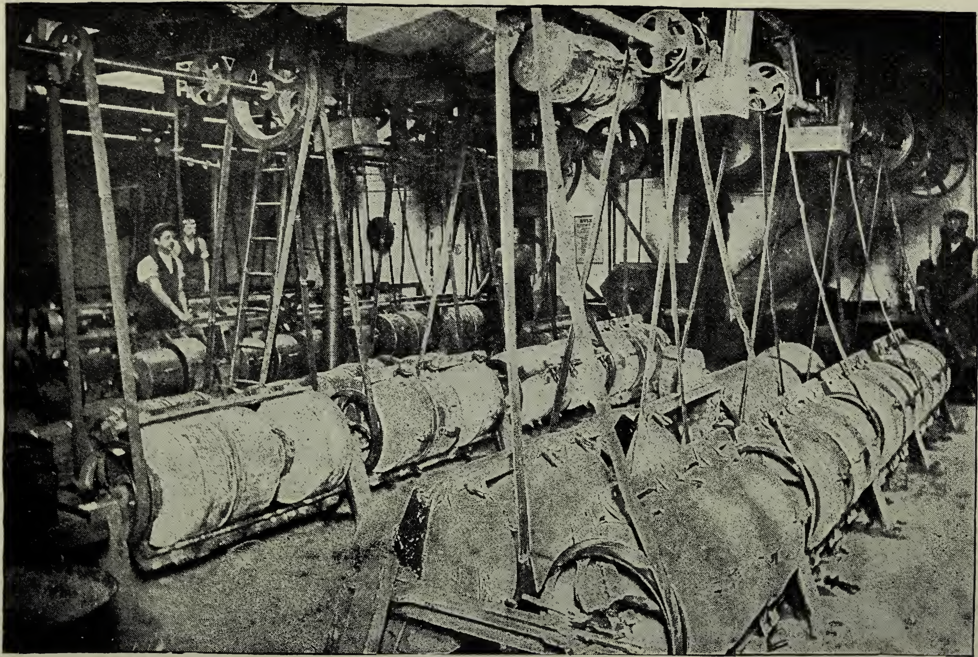


FIG. 158.—In the Scouring-mill. Drums containing the pens and polishing materials being revolved by belting.

The shaking-mill, where the scouring is done, is the noisiest part of the factory. From every drum proceeds a loud hiss, as of water escaping from a pipe under high pressure.

GRINDING.

If you examine a box of assorted pens, you will see that many of them are marked with fine longitudinal lines about the ink hole or "pierce," and with cross lines nearer the tip. This marking is not done for ornamentation. The "straight" grinding at the "pierce" slightly thins the metal and increases its elasticity; the "cross" grinding roughens the surface and helps to prevent the ink from flowing downwards too rapidly and forming blots on the paper. Grinding is performed by girls with the aid of a "bob"—a disc of a special kind of wood two inches thick, tapered at the circumference to the required width, and faced on the edge with a piece of leather dressed with emery powder. The bob revolves at very high speed, and the operator, holding the pen firmly on a prepared stick, grinds off a portion of the surface by touching it lightly against the bob.

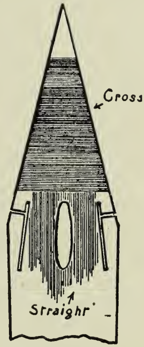


FIG. 159.—Showing "straight" and "cross" grinding of a Pen.

SLITTING.

Dip your pen into the inkpot and press it against a piece of paper. The two halves of the point separate slightly, and down this the ink flows by virtue of the tendency of any liquid to work itself into and follow a very narrow channel. This tendency is known scientifically as "capillary attraction." As soon as the pen is lifted from the paper the points close together and check the flow.

Without the slit a pen would be useless. It is a delicate operation to slit a point of tough metal and yet not spread the two parts. The tools by which it is carried out are termed "cutters," and consist of two pieces of steel about $1\frac{1}{2}$ inches long, $\frac{1}{2}$-inch thick, and 1 inch wide, having edges as delicate as a razor. They are adjusted in a press so carefully that the upper one as it descends does not touch the lower, but as it passes by it would remove from it even the tiny film of moisture caused by breathing on the surface.

The pen is laid on a rest with the point lying on the lower cutter. The operator then pulls the handle of the press, which makes the upper cutter come down and part the steel accurately along the centre line.

Some pens, on account of their irregular shape, require special cutters and rests of a rather complicated form.

POTTING, COLOURING, AND VARNISHING.

"Potting," which follows immediately, smooths off the keen edges of the nibs caused by the slitting. It differs from the scouring of tempered pens only in the material used in the drums. After this the pens are revolved in iron cylinders with a small quantity of small quartz pebble and slightly roughened. Then they are dipped in a bath of shellac varnish, allowed to dry, and "stoved" to set the varnish. It is the presence of the varnish that makes it necessary to suck a new pen before use, the slightly acid saliva of the mouth readily dissolving the very thin anti-damp coat of shellac.

The finished pen finally undergoes a searching examination by trained experts. Each of these has a little block of ivory attached to her left thumb. She (*a*) takes the pens, three at a time, and examines the letter-marking, piercing, etc.; (*b*) picks up each pen by the "heel," or holder end, and tries the points on her thumb-piece for the slitting and grindings (if the points do not close properly the pen is rejected); (*c*) examines the points to see that they lie quite

level. This is effected by holding the pen sideways to the light. If one point is higher than the other it casts a shadow.

So thorough is the examination, and so high is the standard required, that of ordinary pens only from 80 to 82 per cent. are passed on an average; and in the case of the fine lithographic pens referred to in an early paragraph the proportion sinks to 25 out of 120, or about 20 per cent. In spite of these rejections, a million pens are boxed weekly by the makers for sale in all parts of the world.

Chapter XXIV.

IN NEEDLE TOWN.

The qualities of a needle—Early history of the English needle industry—Redditch the present centre of the industry—Manufacture of a needle—Straightening of the wires—Pointing on a grindstone—Skimming—Eyeing—Filing—Hardening and tempering—Scouring—Heading—Grinding—The calyx-eyed needle—Fish-hooks—Barbing—Bending—Finishing.

TAKE an ordinary sewing-needle and look at it carefully. The point, very sharp, is tapered symmetrically. Hold the eye up against the light, and you will see that the metal on each side of it is very thin—wonderfully thin, in fact—in order that the eye part (the head) may be no larger in diameter than the shaft. The eye itself is smooth inside, so that it may not fray the thread, and for the same reason slightly rounded at the edges. The exterior has a high polish. Taken altogether, the needle is a beautifully conceived and finished article; and as a penny, or even a halfpenny, packet contains a dozen needles, they are marvellously cheap. "If we take

a needle of 1837—there are a few about, kept as curiosities—we shall see a shaft thick and badly formed, white in colour, and scratched as if polished with emery paper, the point irregular, one side flatter than the other, the head considerably larger than the body of the needle, with an eye perfectly circular, roughly drilled out, and deeply countersunk round the edge." This quotation applies to old-fashioned English needles, which in their turn were immeasurably superior to the crude articles used to-day by uncivilized races.

As sewing plays a very important part in providing us with our very necessary clothes, the making of needles must be regarded as an important industry. For a reason that is not plain, the county of Worcester practically monopolizes this particular manufacture, and has done so for several generations, though the original seat of English needle-making was Long Crendon in Buckinghamshire, where one Christopher Greening started a business in 1650. Thence the trade migrated to Worcestershire, and settled down in Redditch and the neighbourhood.

Redditch was, till recently, scarcely more than a large village. Now, thanks to its many factories, which include a growing number devoted to the

construction of cycle and motor parts, it has attained the dignity of a small town. Some 20,000 people in the neighbourhood make a living out of needles, millions of which leave the factories every week. Families have stuck to the trade for generations, and the needle-makers are, we learn, a very steady and moral folk.

When you consider the delicacy of a needle, you will not be surprised to read that its manufacture demands no fewer than *twenty-two distinct operations.* Most of these are performed by women, whose deft fingers are better suited to the handling of such minute articles than are the stronger but more clumsy digits of the other sex. The latter find employment in the processes which require strength combined with endurance.

The material out of which needles are made is fine steel wire drawn specially for the purpose at Sheffield. The manufacturers of the wire cut it up into lengths, to form two needles each. The first thing that the Redditch people have to do is to "rub" the lengths, known as "wires," to straighten them. A bunch of wires is slipped through two iron rings and placed in a furnace. When heated to

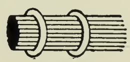


FIG. 160.—Bundle of Wires ringed for rubbing.

a dull red the workman draws them out, places them on an iron-topped table, and with a curved bar, called a "file," presses on the wires and rolls

FIG. 161.—Rubbing Needle Wires to straighten them.

the bunch to and fro. Repeated contact with the file and continuous movement over one another soon remove the coil curve from the wires (Fig. 161).

Next follows the important operation of

POINTING.

Formerly pointing was done by hand. The "pointer," holding some dozens of needles in his left hand, pressed them against the surface of a grindstone, simultaneously rolling them with his right hand. A good workman could in this manner point some hundred thousand needles in a day. He was well paid, because, in spite of the muffler which he wore over his mouth, he inhaled the fine particles of stone and steel caused by the grinding, and so ran very grave risks of falling a victim to consumption at an early age. The machines used nowadays are both more effective and more sanitary. The grindstone has a concave face. At right angles to the grindstone, and almost touching it, revolves a rubber-covered wheel of such a diameter that its face almost

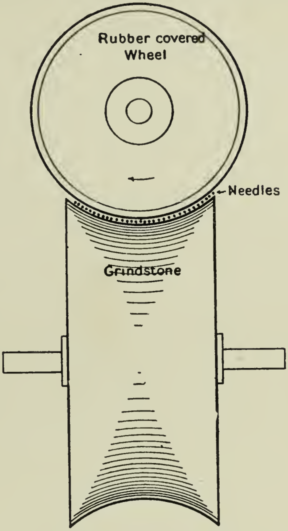


FIG. 162.—Diagram showing how Needles are pointed.

touches that of the grindstone right across the curve. Into the space between wheel and stone, wires pass in a continuous stream from a hopper, and are moved across the face of the stone by the clinging rubber, which also revolves them. At any one moment one end of a hundred or more wires is being pointed; and the sparks, flying off in millions, give a very bright and dazzling display, though if the hand be plunged into the fiery shower for a few moments no sense of heat is experienced. All the dust from the wheel is sucked by an artificial draught into the mouth of a large pipe, and so is prevented from doing any damage to the machine-tender.

As soon as one end of a "packet," or batch, of wires has been pointed, the other end goes through the same process.

SKIMMING.

Except at the points, the wires are dull from the heating previous to rubbing. At the middle, where the two eyes for the pair of needles will be made, it is necessary to remove the "scale," or outside skin, lest it should affect subsequent processes. The skimming, or removal of scale, is done by a machine with three wheels, two of which press the wire

against the emery-coated edge of another wheel revolving more rapidly between them.

STAMPING.

The skimmed wires are now transferred to a device which feeds them one by one from a hopper on to the edge of a grooved wheel rotating close to a fixed die. As each wire comes to the die it is lifted off and held for a moment against the die, while a moving die deals it a severe blow, which flattens out the centre and impresses two oval dents in it close together on both faces of the "flat." The wire is then thrown off the rest automatically into a receptacle below. "It is necessary that a deep impression should be made on each side of the eye—first, as a guide for eyeing; and secondly, because the punches could not pierce the wire without its being previously thinned just where the eye is to come. The process of stamping also makes a countersink round the eye; and if there is to be a groove of any kind leading up to the eye of the needle, it fashions that too."

Stamping is sometimes done by hand. "In this operation the workmen acquire wonderful dexterity. They stamp the wires with such rapidity, passing them from one hand to the other and letting each

fall silently into the receiving pan when finished, that they appear to be stamping the same needle all the time. The men engaged in this work average between twenty-seven and twenty-eight thousand wires a day, which is not very much slower than the machines."

EYEING

is the most interesting process of all. Women do it either by the aid of an automatic machine or in a screw press. The machines catch the wires on two endless revolving screws and carry them in succession under two tiny punches of exactly the same shape and size as the impression made by the stamps. The punches descend and press out the superfluous metal in just the same way as the piercer used in penmaking. The most notable point about eyeing is the accuracy with which the wire is presented to the punch. It is quite obvious that if the wire were not quite square to the tool an oblique hole would be made and the wire be spoilt. The dies and beds used for eyeing are so very minute that we can well understand that many years of training are required to teach a workman the art of fashioning them correctly.

Some kinds of needles are eyed in hand presses.

Though these do not treat nearly so many needles as the machines in a given time, expert hand-eyers will eye twenty to twenty-five thousand wires a day.

The double needles are now *spitted* in groups of

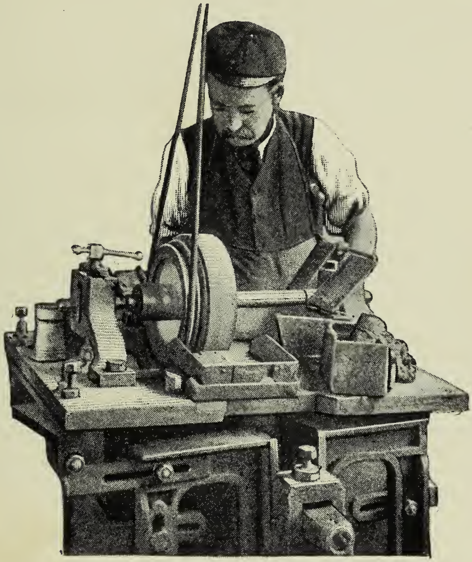


Fig. 163.—Pointing Needles.

several hundred each on a couple of wires passed through the eyes, so that a group resembles a very fine-toothed, double-edged comb. A workman called a filer takes a group, presses the ends under a couple of steel springs to hold them down, and files off the

"burr," or roughness, round the eyes caused by the stamp pressing out a little of the metal. This completed, he releases the wires, and holding one end in each hand, bends them backwards and forwards until they separate between the eyes and each wire becomes two distinct needles. The eye ends being rough and jagged, the filer clips the points of a row in a vice, and rounds the heads off neatly with a file, after which the actual "making" may be considered finished.

But the inside of the eye is still rough; the metal is so soft that you may bend the needle about in your hands quite easily; and the outside is rough and partly dark.

The eyes are burnished internally by stringing the needles on fine wires slightly roughened, and suspended on little upright bars of iron projecting from a table. This table is given an oscillating motion, and the needles, sliding backwards and forwards on the wire, have their eyes nicely smoothed. This process is called "wire-burnishing."

HARDENING AND TEMPERING

call for no special notice here, as they are effected in the manner already described in the chapter on pens.

It should be observed, however, that great care is required, as few things are more worthless than a badly-tempered needle. It soon communicates its own bad temper to the unfortunate user.

SCOURING,

which follows, also has its counterpart in pen-making. But as the differences are considerable, let us see how needles are cleaned and polished. "They are laid, together with emery powder and soap, on pieces of canvas, which are rolled up so that they somewhat resemble sausages. These rolls are then placed under heavy slabs of wood, known as 'runners,' which are worked backwards and forwards on strong tables by cranks. A roll is placed under each end of the runner, and the latter is then started and kept going—with the exception of taking the roll out now and then to moisten it—for twelve hours at a time. This process is repeated some four or five times. When finished, the needles are taken out and well washed, and all scale having been removed by the friction, they now appear white. They are again made up into similar rolls, but this time using solution of 'powder.' The rolling process is gone through, and when they are finally stripped of their covering, they are found

to have acquired a 'glaze' or 'colour,' which gives them, though highly polished, a beautiful, dark appearance. They are washed again, and sent back to the factory. On an average, each packet of needles is nine days in the mill."

The many operations have unavoidably damaged some needles. These must be removed, and for this work great deftness is required. The sorter spreads the needles out and rolls them about with her fingers, flicking out any one that is in the least crooked, marked, broken, or otherwise defective.

Now comes the

HEADING

—that is, arranging the needles, which lie all ways like a heap of spillikins, so that all the heads may point in the same direction. The workwoman first arranges them in rows, and then, enveloping the forefinger of her right hand in a piece of rag, presses it against one side of the row. At the same time she presses the other side with the palm of her left hand. All the points on the right side are driven into the rag and withdrawn by it; and so the needles are gradually separated into two sets, duly arranged.

It is also of importance that all short needles should be removed from the packet, or group of fifty

thousand or so, according to size, and put with others of equal length. The sorting is done either by hand or by machine. In the first case, the operator lays the needles side by side on a hollowed-out piece of wood, somewhat narrower than the length of the needles, presses her palms gently against the ends, and lifts some up. A gentle shake causes those which are too short to fall; the longer ones stick to her hands. If, however, a machine is used, the needles are fed from a hopper on to a broad wheel grooved across the face. The grooves take the needles from the hopper and carry them through a series of gauges, until each encounters one a bit too narrow for it to pass, and is ejected into a pan. Another machine does the counting. Each needle in passing through it moves a cog-wheel operating a train of wheels which work a pointer on a dial-plate. In this way two thousand needles can be counted in a minute, each two thousand constituting a "dab."

GRINDING.

The sorted needles now only need to be finished off. The tops of the heads are smoothed on a stone, the points sharpened on grindstones, the edges of the eyes smoothed off by pressing the eyes against pin points

stuck in a wheel revolving at high speed, and the whole of the surface polished on cylinders of leather.

Packing in sets of ten, twelve, or twenty-five, and labelling follow, and the needles are ready for the market.

The smallest needles are about as thick as a hair, and half an inch long. These are used by glovers, and weigh forty thousand to the pound. Besides the ordinary sewing-needle, Redditch produces a multitude of types for special purposes—the curved surgeon's needle, the packing-needle, the upholsterer's needle, needles with a point at each end, triangular sail needles, square sack-sewing needles, nickel-silver and phosphor-bronze needles for making gunpowder bags.

The calyx-eyed needle, of which we give illustrations (Fig. 164, *a* and *b*), is a very interesting type. It may be described as a needle with two eyes and a forked head. The head is slit down to the second eye so neatly that one can hardly see the slit. To thread the needle, the thread is pressed into the fork and drawn smartly downwards into the first eye. The slit between the eyes, and the second eye itself, render the sides of the head more elastic. The thread cannot pass beyond the first eye, as the sides fly together immediately it enters, and close the slits.

You are now in a position to understand that the needle, although small and cheap, has somewhat remarkable antecedents. There are few, if any, one-piece objects in common use which pass through so many various processes while being converted from the raw material into the finished product, or gain so greatly in value by the conversion.

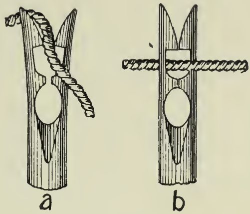


FIG. 164.—*a*, Calyx-eyed needle being threaded ; *b*, threaded.

FISH-HOOKS.

Sewing-needles and fish-hooks have this much in common, that they are slim and sharp-pointed. They differ in that the first are straight, tapering, and easily withdrawn ; while the second are curved, and furnished with a barb which makes them stick fast in anything they may catch hold of.

I append a short description of fish-hook manufacture to close this chapter, for the reason that Redditch is the chief seat of the fish-hook-making industry, and because I think that possibly any reader who is a disciple of Izaak Walton may be interested in the origin of this most important item of his outfit.

Fish-hooks are made from the very finest steel

wire. This is cut up into proper lengths, and the lengths are *barbed*, either before or after *pointing.*

When pointing precedes barbing, it is done on a machine similar to that used for needles. A hook made in this way is called a "dub." If barbing comes first, the point has to be made by hand, or in a machine which first cuts the wires from the coil and straightens them. The cutting of the barb is effected by pressing a sharp knife obliquely against the wire.

Bending. A steel mould, of the exact shape that the hook is to take, and sharp where the barb of the hook fits on to it, is attached to a block which can be rotated on a central pivot by a handle. A number of wires having been placed in this mould with their barbs caught by the sharp edge, the worker grips the other end of the wires in one hand, and revolves the block smartly, pressing the wires tightly against the mould. This gives each wire the shape of the exterior of the mould. To prevent the line from slipping off after being tied on, some hooks are flattened at the shank in a stamping press, or have the end of the shank bent into a ring; others have the shank filed off to a point *before* bending. Then follow in order *hardening*, *tempering*, *scouring* in revolving barrels

partly filled with water, *drying* in sawdust, and *blueing* in a pan held over a fire, or japanning. Sea hooks are sometimes tinned (instead of being blued) by immersion in a bath of molten tin.

Hooks with rings at the end are ringed before hardening.

The processes are the same whether the hook be a tiny thing intended for river fishing or the huge implement—such we may justly call it—that will be hidden in a lump of pork to catch the hungry shark of tropical seas.

I cannot close this chapter without acknowledging the help derived from a booklet published by Messrs. Henry Millward and Sons, Redditch (from which the quotations are made); and my indebtedness to Messrs. J. English and Co. for permitting me to see in their factory many of the operations described above.

Chapter XXV.

SCREW-MAKING.

Old-fashioned screws—The gimlet-pointed screw—An interesting Roman screw—Processes of manufacture—Forging—Trimming and nicking—Cutting the screw thread—Nail-making.

IF you wished to drive a carpenter's screw through a plank of soft wood, you would probably first bore a small hole with a bradawl or gimlet for the screw to follow. But this is only to guide it, since the screw can worm its way into the wood in the same way as a gimlet does. Now, I have by me some screws that I once took out of a piano, a hundred years or so old. These are blunt-ended, like screws used in metal work, and you could not get them to enter wood unless you prepared the way for them by making a hole of almost equal diameter.

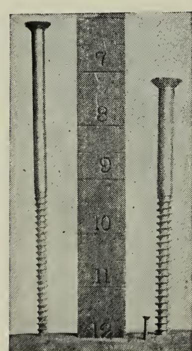


FIG. 165.—A 6-inch, a 5-inch, and a ½-inch Screw.

Of course no carpenter would think of using any but a gimlet-pointed screw nowadays, as it is so vastly superior to the older type. And when I say older type I must be careful, since there is in the Silchester Collection at the Reading Museum a genuine Roman screw (Fig. 166), which has a tip very closely resembling that of the famous Nettlefold

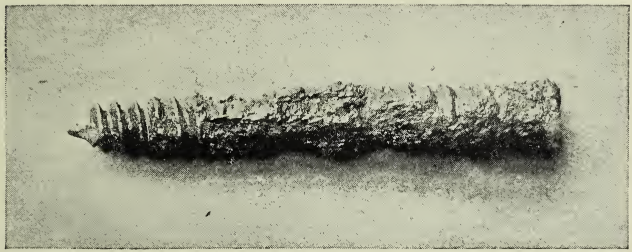


Fig. 166.—A Roman Screw discovered at Silchester. Observe the gimlet point. (*Photo by V. White & Co., Reading.*)

patent. So that it would perhaps be correct to regard the modern tip as an invention revived.

By the courtesy of Messrs. Butler and Spragge, of Cambridge Street, Birmingham, I was allowed to acquaint myself with the very interesting processes used in the manufacture of carpenters' screws.

They are three in number—(1) the making of the "forging;" (2) the trimming and "nicking" of the head; (3) the cutting of the thread on the shank.

FORGING.

We enter first a long chamber filled with noisy presses of different sizes, some for forging screws up to 6 inches in length and $\frac{3}{10}$ of an inch thick, others for very small articles half an inch long.

At the end of each press is a coil of steel, brass, or copper wire of the gauge required for the dies in that particular machine. A simple diagram or two will put you in possession of the main details of a press.

In Fig. 167 J J are a couple of jaws which grip

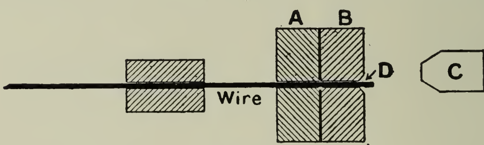


FIG. 167.

the wire as they move to the right, but loose their hold as they move to the left. A is a *fixed* block pierced with a hole the size of the wire; B is a *movable* block, also pierced, and having a countersink D on the outer face. C is the "hammer," worked by an eccentric on the shaft of the heavy flywheel of the press.

The jaws have pushed the end of the wire some

distance beyond the die B, to allow sufficient material for the head. Immediately the wire is in position B is forced sideways, shearing the wire, and bringing the detached portion opposite the centre of C, which delivers its blow and squeezes the protruding end into the countersink (Fig. 168). Then B returns to

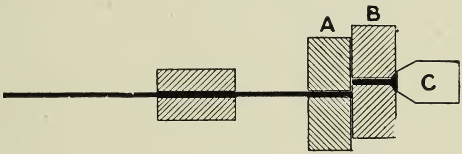


Fig. 168.

its original position, and the next stroke of J J causes the wire to force out the headed "forging" (Fig. 169). Small screws are made at the rate of about one hundred and twenty per minute.

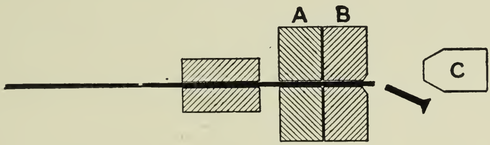


Fig. 169.

In the case of round-headed screws, the shaping of the head is done by a cavity in the face of the hammer C, and B has no countersink.

The forgings are polished by sawdust in revolving barrels, and sent to be trimmed and nicked.

TRIMMING AND NICKING.

The machine used for this process is extremely ingenious. At the top is a revolving, funnel-shaped hopper filled with forgings. A steel fork mounted on a standard dips periodically into the hopper, gathers up any screws that lie the right way, and tips up, shooting its load down a channel which leads to the cutting machinery. If the "feed" overtakes the cutters and the channel is filled, the fork is locked automatically, and prevented from descending until more forgings are required.

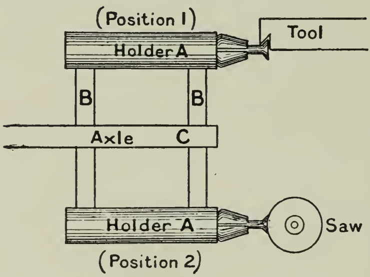


FIG. 170.—Machine for cleaning and slotting the Heads of Screws.

I must now ask you to look at Fig. 170. On an axle C are two arms B B, carrying two pairs of jaws A A, acting in much the same way as a well-known type of pencil, which allows the lead to fall out if you press in a spring at the rear end. When a forging reaches the bottom of the feed groove, a mechanical clip seizes it and presents it to a pair of jaws. (Position 1.) These grip it tightly, while

a cutter advances and trims up the surfaces of the head. Then the frame revolves through half a circle, and brings the head opposite a circular saw, which travels across the end and makes the nick. (Position 2.) The frame then completes the circle, dropping the forging on the way.

While one forging is trimmed another is nicked. The machines are so completely automatic that only one attendant is required for thirteen of them, just to keep them supplied with forgings, and to see that the "feeds" are not choked.

After a second polishing in sawdust, the forgings go to the

THREADING MACHINES.

These are fed in the same way as the nickers, by automatic forks, but have only one pair of jaws, which grip the forging by the *head* and revolve it. A cutter first turns the end to a conical shape, and then a chisel attacks the side of the shank.

It moves slowly along towards the tip, removing a thin strip of metal. On reaching the conical portion, it is forced nearer the axis of the screw by a guide and forms the gimlet end. Then it is withdrawn, moved away from the screw, and returned to its first position for a second cut. After six to

eight journeys, according to the size of the screw, the thread has been chased to its full depth, and the now completed article is expelled to make room for its successor.

The screws are polished and sorted. All forgings that have escaped the slotting saw are returned to the machines, and all imperfectly threaded screws are thrown away. Finally, a girl weighs the screws into grosses, and packs them in cardboard boxes, ready for the consumer.

NAILS.

Round-shanked nails, such as wire or "French" nails, are made out of wire by a process somewhat resembling the forging of screws. The main difference is that the wire is gripped during the "heading" by a pair of jaws—which leave marks on the shank just below the head—and subsequently cut off to a point. There is no moving die.

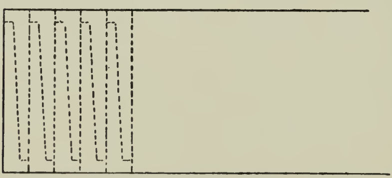
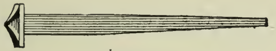


Fig. 171.—Showing how Floor Brads are stamped out of sheet iron.

Floor brads (Fig. 171) are *stamped* direct out of sheet metal, the heads lying alternately on the right and left edges of the strip so that there may be no wastage.

Cut "clasp" nails (Fig. 172) are cut out of a strip, which is turned over between every two cuts to avoid wastage. The heads are formed after cutting.



Clasp.

Fig. 172.

Rose

Fig. 173.

"Rose" nails (Fig. 173), tinned tacks, and other varieties of tapering nails, are cut from the end of strips thicker at one edge than at the other.

Chapter XXVI.

PINS.

Adam Smith on the division of labour as illustrated by the manufacture of pins—The modern development of the industry—Pin-making machines—How a pin is pointed—Machine *versus* hand labour—Cleaning the pins—Applying a coat of tin—An ingenious apparatus for sticking pins in paper—Black pins—Safety pins.

IN the first chapter of his famous treatise on political economy, entitled "The Wealth of Nations," written about the year 1765, Adam Smith sets out to prove that labour may be made very much more productive if the various processes of manufacture are specialized, one man doing one thing only, instead of endeavouring to begin and finish an article himself. He selects the pin industry as typical by illustrating the advantages arising from the system of distribution of labour. "A workman not educated to this business (which the division of labour has rendered a distinct trade), nor acquainted with the use of machinery employed in it (to the invention of which the same division of labour has probably

given occasion), could scarce perhaps, with his utmost industry, make one pin in a day, and certainly could not make twenty. But in the way in which this business is now carried on, not only the whole work is a peculiar trade, but it is divided into a number of branches, of which the greater part are likewise peculiar trades. One man draws out the wire; another straightens it; a third cuts it; a fourth points it; a fifth grinds it at the top for receiving a head; to make the head requires two or three distinct operations; to put it on is a peculiar business; to whiten the pins is another; it is even a trade by itself to put them into the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which, in some manufactories, are all performed by distinct hands, though in others the same man will sometimes perform two or three of them. I have seen a small manufactory of this kind, where ten men only were employed, and where some of them consequently performed two or three distinct operations. But though they were very poor, and therefore but indifferently accommodated with the necessary machinery, they could, when they exerted themselves, make among them about 12 lbs. of pins

in a day. There are in one pound upwards of four thousand pins of a middling size. Those ten persons therefore could make among them upwards of forty-eight thousand pins in a day. Each person therefore making a tenth part of forty-eight thousand pins, might be considered as making four thousand eight hundred pins in a day. But if they had all wrought separately and independently, and without any of them having been educated to the peculiar business, they certainly could not each of them have made twenty, perhaps not one pin, in a day—that is, certainly, not the $\frac{1}{240}$th, perhaps not the $\frac{1}{4800}$th part of what they are at present capable of performing, in consequence of a proper division and combination of their different operations."

You will gather from the above quotation that the art of pin-making, as practised in the later part of the eighteenth century, was complicated and laborious. The common dress pin is now used in so great quantities, and for so many purposes, that, owing to the need for cheap production, the very industry which Adam Smith singled out to illustrate his contention about the division of human labour has since his time seen some of the most remarkable developments in the direction of replacing

human labour by machinery. It is estimated that about five hundred million pins are now manufactured weekly, the larger part of them in Birmingham, their value being some £500,000 sterling. Where they all go to is a mystery, as they are not breakable like a needle. We should doubtless be greatly surprised if we were suddenly gifted with the power of seeing clearly all the "lost and strayed" pins that litter the earth's surface.

The first practical pin-making machine was introduced in the year 1838, and the machines in common use at the present time are practically all developments of it. I had the pleasure of seeing some pin-making machines at work in the factory of Messrs. George Goodman and Co., Caroline Street, Birmingham.

The material out of which most pins are made is brass wire, drawn to gauge through dies. The wire is done up into a coil, which is placed on a reel at one end of the machine. An extremity of the wire is passed through a hole in a plate to straighten it, moved forward between iron pegs which keep it straight, and into the jaws of a pair of mechanical pincers, which grip and hold it while a little hammer gives the protruding end

three sharp blows and moulds it to the shape of two countersinks in the pincers and the hammer-head. Then down comes a shears and snips off the length of a pin, the jaws open, the wire is moved forward, and the headed forging, or blank, as we may call it, is expelled to make room for its successor. So far the process is very similar to that of making screws, described on page 402.

The blank falls into a space between two plates set at such a distance apart that they allow the shank, but not the head, to pass. The groove thus formed leads the blanks down the side of the machine and across the face of an almost horizontal circular file revolving at high speed. By means of a special mechanism the blanks are moved backwards and forwards in front of this file, but they are allowed to touch it only during the motions towards the exit end. This combined filing and rolling gradually wears away the end of each blank into a fine point, and the pins are constantly expelled, a few at a time, into a pan to make room for blanks entering the groove. From one hundred and fifty to one hundred and eighty pins are pointed in a minute, so that a machine working ten hours a day is able to turn out a total of from ninety

to one hundred and eight thousand. As a single attendant can look after at least ten machines, one person suffices to conduct a million pins daily from the wire to the pointed stage. This would surprise worthy Adam Smith were he to appear suddenly in a Birmingham factory.

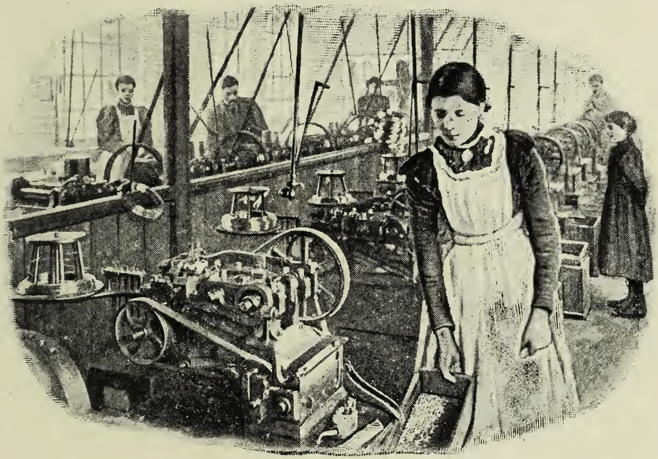


FIG. 174.—A Pin-making Machine at work.

The pins as they issue from the pointing-machines are greasy, and of a dull yellow colour. Even if cleaned they would not be fit for ordinary use, since brass forms with the oxygen of the air an unpleasant substance called verdigris, which would mark any substance through which the pins might

be stuck. Therefore they are cleaned by being placed in revolving barrels, and then laid in steam-heated kettles and covered with a layer of finely-powdered tin and acid. In this mixture they are boiled for about four hours, and when they are taken out the yellow surface

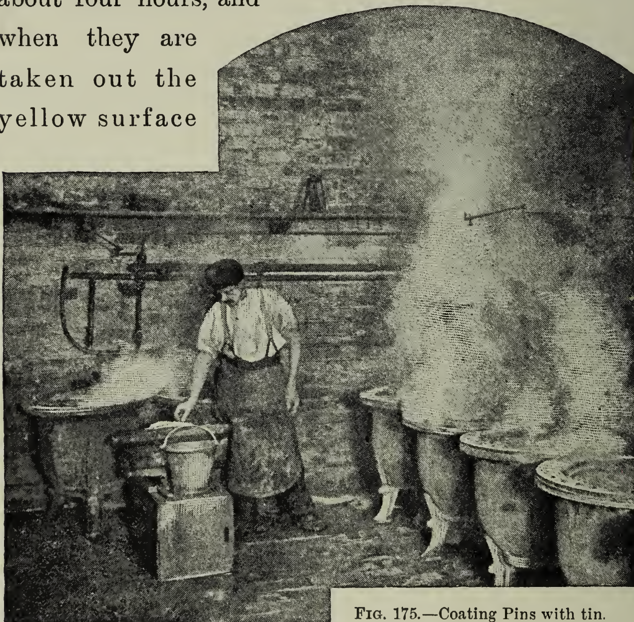


FIG. 175.—Coating Pins with tin.

has disappeared, giving place to the beautiful silvery exterior with which we are so familiar. Having been dried in sawdust, polished in revolving barrels, and freed from dust by tossing in trays, they are

carefully sorted and sent to the sticking-machines. These machines are wonderfully ingenious. They lead the pins, points downward, from a hopper down a number of parallel grooves and bring them in rows under the edge of a thin flat bar, which presses one row at a time down into the fold of a

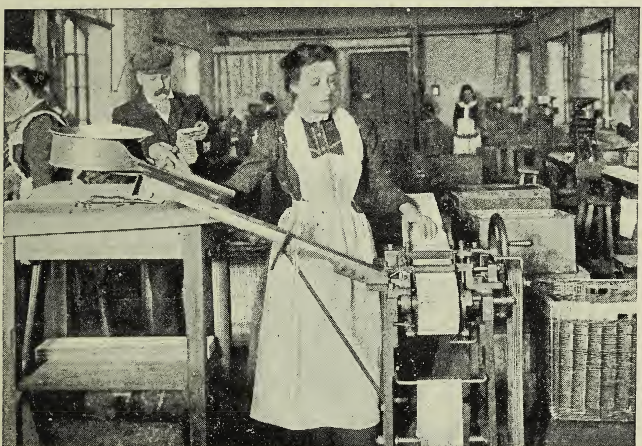


Fig. 176.—Sticking Pins into papers.

paper strip, which is simultaneously crinkled to receive them.

It should be noted, however, that a large proportion of the pins are put up loosely into packets and boxes, as they occupy less room when thus packed.

Black pins are made of steel wire, and japanned by immersion in pans of enamel. After being dried in a stove they are finished.

Safety pins. The wires for these, having no heads, are pointed in the same way as needle wires, by being rolled across the face of a concave grindstone. The catch is formed out of a piece of thin metal plate, punched out and bent to shape by a clever apparatus. Another machine takes the pointed wires and gives them a single turn in the middle to form the spring, and also bends the blunt end over to engage with the catch. Safety pins were well known to the Romans, and if ever you are in the British Museum be sure to visit the Central Saloon and have a look at the many fine specimens to be seen in the cases there.

Chapter XXVII.

HOW TWINE AND ROPES ARE MADE.

Useful string—Materials employed in the manufacture of twine and rope—A "rope-walk"—Preparing the materials—Carding, drawing, and spinning—A few words about twisting—Polishing twine—A balling machine—Rope-making—Twisting the strands—Laying three strands together to form a rope—A very big rope—Summary.

IT used to be said that if you explored the pockets of any schoolboy who had not passed his early teens, you would be pretty sure to find in them a top, a piece of string, and a knife—the second, presumably, being used to spin the first. But, "Have you got such a thing as a bit of string about you?" is a question put commonly to people of all ages, as one is so often in need of a piece of that useful commodity; and schoolboys are certainly not the only folk who carry twine about with them on the chance of its coming in handy at some time or other.

Twine and its bigger brothers cord, rope, hawser, and cable, serve a thousand purposes, and are so

generally valuable that for their own sakes they should not be passed over; while from the author's point of view they appear worthy of inclusion because probably few out of the many users—among landsmen, at any rate—know how they are made.

The materials used in their manufacture are *hemp*, *jute*, and, for rope, *coir*. The two first are the fibrous parts of the stems of plants that grow chiefly in India, the Philippines, Russia, and New Zealand; the last is the fibrous casing or bark of the cocoanut. Hemp makes the best twine or rope; jute has less strength, and is therefore employed for the commoner forms of coarse twine used to sew sacks, bind corn, etc.

Beside the Great Eastern Railway, at Coburn Road, about two miles from the Liverpool Street terminus, is an old-established "rope-walk," where all classes of goods are made, from a fine twine to a cable eight inches in diameter. The proprietor, Mr. J. T. Davis, kindly invited me to visit his "walk," and allowed me to roam about on a tour of investigation.

The premises are divided into two main parts—the walk proper (a long, low shed beside the railway embankment), and the mill in which the raw materials are prepared, and where twine is spun.

The hemp, jute, etc., arrive at the walk in large bales. The various materials vary widely in texture, some being soft and glossy, others hard and stubborn; and of none can it be said that they look "promising" for conversion into excellent ropes and twine.

The bales having been opened, the contents are tossed into preparing machines and well kneaded by powerful rollers. Hemp is torn asunder by twisting the ends of a quantity over two square-ended shafts revolved in different directions by powerful gearing. Then the loose stuff passes through very clever machines containing spiked belts which comb its fibres lengthways and form it into "sliver," which comes off as a continuous thin glossy band, and coils itself up in a deep can placed at the exit end. The sliver is fed from the can on to a spinning-machine, drawn through a hole in a die, and attached to a bobbin which turns head over heels very fast across the machine, and simultaneously revolves slowly on its axis to give the necessary drag to the sliver and gather up the spun "yarn." The thickness of the yarn depends, of course, on the thickness of the sliver.

The yarn is transferred from these bobbins to the bobbins used in the twine-twisting machines or the rope-walks. The yarn, be it understood, is the founda-

tion of all twines, lines, cords, ropes, and cables, the size of the finished article depending merely on the number of yarns which it contains. For the sake of lucidity, I may here mention that all kinds of cordage which exceed one inch in *circumference* are known collectively as "rope," and that the word "cable" implies that three or more ropes have been twisted together. The term "lay" which will occur in the following description is the ropemaker's name for the length of a twist. If you held a finger on one point of a strand of rope, and traced that strand round to another point in line with your finger, and the distance between the two points was six inches, that rope would have a "6-inch lay."

TWINE AND CORD MAKING.

From the rattle and roar and dust of the combing and spinning departments we ascend a staircase to the twine-room. Here machines of various types are in operation. The bobbins of yarn are mounted in circular frames which revolve at high speed, and pay out their respective yarns through a tube, twisting over one another at the point of entry. Please note that if the yarns were given a left-handed twist when spun, the twine yarns are twisted together

right-handed, so that the yarn fibres may not be further twisted, but rather untwisted. Should three strands of yarn be "laid" together into a rope, they will be turned to the left; and should the process be continued another step, and three ropes be put together, the twist would again be right-handed. A certain amount of twisting compacts the fibres, but any excess tends to weaken and rupture them.

Well, then, here we see a machine putting together a dozen yarns into a strand $\frac{1}{8}$-inch in diameter. This we should call twine, being small. Another machine twists together three of these strands into a small cord. I have before me on the table a piece of common box cord. Let me see how it was made. Holding one end towards me, I give it a clockwise twist (that is, one in the direction in which the hands of a clock travel), and three strands reveal themselves. But the individual strands only tighten if I twist them that way; so I give them an anti-clockwise twist, and find that each contains a dozen yarns, each of which needs a clockwise turn to unravel it. So I can easily prove to my own satisfaction that what I was told and have told you is correct. The twine, line, or cord as it leaves the machines is rough and hairy, whereas any sample

Fig. 177.—A Coil of 7-inch (diameter) Rope.
(*Photo by J. T. Davis.*)

that you may have by you is sure to be more or less smooth and polished on the outside. The improvement is effected by unwinding the twine, etc.,

off the machine bobbins through a trough of hot water, and over a set of rubbing rollers turning rapidly in the reverse direction to the travel of the twine. Then it goes through a bath of size, passes between rollers which squeeze out most of the coating it has picked up, and over a big steam-heated drum, which dries it. A final scrubbing by rollers covered with coarse coir matting renders it fit for balling.

I am sure that we all admire the neat winding of a ball of string, and I confess I was interested to see how it is done. The winder is a horseshoe-shaped affair, with two arms that partly encircle a spindle, revolved at one end by gearing. Through one of these arms the twine is fed from the bobbin. The spindle can be moved about horizontally between the arms by a lever. Now watch this girl. She points the spindle at the axis on which the arms revolve, and begins by winding a few layers of twine. Then, seizing the lever, she moves it about slowly, so that the twine passes diagonally on to the growing ball, no two turns falling on to the top of one another. I wonder I didn't think of it before: the method is practically the same as that used by a gardener when he does up the garden line, with the difference

that in this case the spindle is fixed and the arm is moved; and, of course, he does not make nearly so neat a job of it as the machine.

When the correct weight has been wound on, the girl gives the ball a few twists about its elegant waist, cuts off and tucks the end under the belt. (This end is easy to find; the other, the interior one, is sometimes rather elusive, and one is obliged to pull out several yards to get hold of it.) The ball is then drawn off at the free end of the spindle.

ROPE-MAKING.

Twine is a very useful article, as we have said, but it has not the romance of rope. The mere mention of rope suggests rigging, salt water, ships being towed and berthed, big loads being hoisted, and many other strenuous operations.

Let us go downstairs again and cross the yard to the "walk," a tremendously long shed—I believe it is 300 yards or more from end to end—open at one side. Down it run three sets of rails, and endless cables which drive machines at both extremities.

The track nearest the wall is used for twisting the strands. A large number (thirty or more) of yarns are drawn off big vertical bobbins, threaded

through an equal number of holes in an iron plate, and pulled through a tube in a massive "fore-end." A twisting machine is run up on the rails, and the ends are attached to a large hook. Then the machine moves slowly backwards, revolving the hook as it goes, so that the yarns are all twisted up together as they leave the tube. In this manner three or more strands can be, and generally are, made simultaneously, for both the "fore-end" and twister have a number of tubes and hooks. The workmen call a completed strand a "ready," because it is ready for "laying" into a rope. As fast as they are made the strands are removed from the twister and hung up on posts beside the walk.

The rope-making machine proper comprises three parts—the stationary "fore-end," which has a number of hooks projecting from the walk side; a "traveller" at the other end, with two large hooks; and a "top machine" between the two.

Two ropes are twisted at once. The workmen take down six strands and attach them, in two groups of three, to six hooks in the fore-end, and then proceed down the walk, laying them over "stake-heads"—removable bars projecting from posts, and furnished with pegs on their upper side to keep the

strands apart. At the farther end of the walk the three strands of each rope (that is to be) are passed through three external grooves of a "top," a block of wood of circular section tapering towards the rear, and hitched on to a hook on the traveller. The last gives the strands a few twists, and the man in charge of the top machine then winds a few rope ends round the strands to keep them well pressed up against the back of the top.

All being ready, he pulls a cord and signals to his mate at the fore-end. The mate moves a lever, and his machine begins to revolve its six hooks—the hooks only turn on their own axes, not round one another—and the same endless cable which moves them also turns the far-away travelling machine hooks at a corresponding pace. It should be explained that the fore-end and the traveller hooks turn in reverse directions, so that the strands may be unwound sufficiently by the fore-end to counterbalance the extra twisting they would otherwise get from the traveller as the strands are "laid" together.

The twisting of the strands presses on the back of the top, and gradually forces it and its carriage towards the fore-end. The traveller is at the same

time drawn forward very slowly by the shortening of the strands as they twist.* Hence its name. As the hooks on it are operated by a pulley turned by the endless rope referred to above, the change of position makes no difference in the speed of twisting.

A boy walking in front of the top, which progresses at the rate of about two and a half miles an hour, removes the stake-heads one after another as the top approaches them; and another, walking behind, replaces them, and lifts the finished rope up on to a series of hooks on the roof supports.

When the laying is completed, the ropes are wound on to large reels, tied up with cord, taken off, and dispatched to their purchaser. I saw in the office a piece of a cable 23 inches in circumference, made of several large ropes twisted together. Such a rope weighs about 125 lbs. per fathom—rope-makers calculate in fathoms—and is capable of standing a strain of over 100 tons.

The yarns of ropes intended for "wet" work are drawn through Archangel tar before being twisted.

To recapitulate the above paragraphs:—Materials:

* A rope is from two-thirds to three-quarters as long as the strands which compose it.

hemp, jute, and coir. These are prepared, combed into sliver, and twisted into yarn. The yarns are twisted into strands, the strands into ropes, the ropes into cables. According to the number and size of strands, and the number of stages of twisting, the same materials may be made into anything from the finest twine to the stoutest cable.

Perhaps the reader may ask, "If you have to make a big rope, why not use a large number of yarns and simply twist them? Why go to the trouble of making strands?" The answer is, that if the yarns in the strand be very numerous, the twisting strain on the outside yarns is much greater than that on the inside yarns, and consequently a pulling strain would be unequally distributed. The ideal rope would have all its yarns parallel to one another.* But such a rope is impracticable for ordinary purposes, and by way of a compromise rope-makers twist the yarns in groups, each small enough to give each yarn its fair share of the work. The twisting presses the fibres closely together, so that water cannot easily penetrate them, and also gives the material a very convenient form.

* The steel cables used in large suspension bridges are invariably composed of a multitude of small parallel wires clipped together at intervals.

Chapter XXVIII.

HOW WIRE IS MADE INTO ROPES.

Tne uses of the steel-wire rope—Messrs. Bullivants' works—Testing a wire and a rope—"Closing" wires into a rope—The twisting machinery explained—A monster machine—Splicing—A hydraulic rope-cutter—A rope that would bear a 1,500-ton strain.

UNTIL about seventy years ago rope was made only of one or other of the vegetable materials named in the last chapter. Improvements in the manufacture of wire have since then brought the metallic rope into great prominence. The steel rope, it is not too much to say, has distinctly widened the possibilities of engineering enterprise. A bar of steel is inflexibility itself; but a steel rope of equivalent strength has sufficient pliability to be handled as easily as a hempen rope. In mines the wire rope is now used for winding and guiding the cages, and for hauling wagons below ground. Wire ropes form part of many large crane tackles. They also draw the steam-plough through the earth, move cable

trams, and, slung on trestles, transport heavy burdens for miles overland. A large book might be written about aerial ropeways alone; and it would make interesting reading, since many of them have been erected in very wild parts of the globe, and in the face of great physical difficulties. Nor should we forget the varied purposes to which the wire rope is put for marine work—to stay masts and rigging, to raise a sunken vessel or tow a floating one, to transfer coal from collier to man-of-war. In the form of a strand it makes useful fences, and whatever the hunting man may think of it, has been of great value to the farmer and stock-breeder in every civilized country. Copper-wire rope constitutes the current-bearing core of the cables which flash messages under the oceans, and distribute light and power on land. In short, wherever great strength and flexibility are needed together, there you will find the wire rope.

Having been much interested in what I had seen of hemp rope-making, I thought I might well go a step further and see how wire is manufactured into rope. In due course I found myself at the works of Messrs. Bullivant and Co., Ltd., at Millwall, where I had the pleasure of inspecting a very fine rope-

making plant under the kindly guidance of a director of the company.

We began with the testing-shop. A good rope brings a good reputation, a bad rope probably means an accident. Samples from every coil of wire used and from every completed rope are submitted to certain tests, the passing of which gives, so to speak, the hall-mark of quality. My attention was first directed to a little machine with which a man was twisting an 8-inch length of wire. A counter geared to the handle registered the number of twists given to the wire before it broke. In this particular case it was thirty-one, proving the wire to be very tough. The broken parts, as I realized on touching them, were very hot, and provided an excellent illustration of the conversion of one form of energy, mechanical work, into another form, heat.

The second test the wire—or rather another sample of it—undergoes is to be twisted eight times round a wire of its own diameter and untwisted. If it will stand this without breaking, its good quality is further proved. Then comes a tension test to find its breaking strain. But as this was performed in my presence on a cable two inches in circumference, I may leave single wires for the moment and say something about

the cable-testing. The apparatus used somewhat suggests by its shape a lever weighing-machine. It has an arm eight or nine feet in length, along which a very heavy weight moves by means of a rope and pulleys. In place of a weigh-pan there is a short arm, which is connected to the sample to be tested. The other end of the sample is attached to a block, movable by hydraulic power.

A rod depending from the free end of the lever passes through a number of iron plates supported above one another, at intervals of a foot, by a frame. Collars on the rod under every plate can be turned round when the beam is depressed, so that one or more plates shall be lifted when it rises. Each plate requires a strain of five tons on the other arm of the machine to raise it from its bed.

The rope sample being in position, an attendant sets in motion the hydraulic pump, exerting a pull on the rope until the long arm rises. The weight is then slid along the scale marked on the side of the arm. If nothing happens, the rope is slackened, the weight runs back, and the collar under the top plate turned. The pump is again set in action, the arm rises, and the moving weight is again wound along; and the process is repeated, a plate

being added to the weight each time until the rope breaks. The breaking strain is quickly calculated in tons by multiplying by five the number of plates lifted, and adding the figure on the lever to which the shifting weight has advanced. The rope which I saw on its trial parted at nine tons odd.

The machine tests up to 150 tons pressure. Even this does not suffice for the largest ropes, and a more powerful 350-ton machine will be installed. My guide told me that the wire can be drawn so as to stand a 150-ton strain for every square inch of solid section, but that it is usual to sacrifice some strength to toughness. Very highly-tempered wire is comparatively brittle.

The results given by every test of wire or rope are carefully entered in a book for future reference, to enable the antecedents of any rope to be traced with ease.

ROPE-MAKING.

Wire ropes, like hemp ropes, are composed of strands twisted together; but whereas in the hemp rope there are usually only three strands, there are almost always six strands in a wire rope, closed on a core of either hemp or wire.

The flexibility of the rope depends upon the

number of wires combined in each strand. For the benefit of the reader we give several sectional illustrations of various kinds of rope. The black portions in every case represent the hemp core, whether in

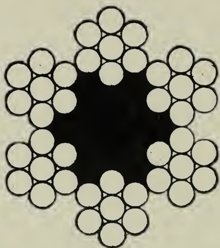


Fig. 178.—"Laid" Rope.

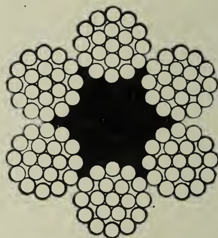


Fig. 179.—"Formed" Rope.

rope or strand. Fig. 178 is a "laid" rope, of the type commonly used for hauling and rigging purposes. It has six strands, each composed of seven wires. Fig. 179 is a "formed" rope of nineteen wire strands, used largely for large-sized standing rigging, and for towing trawl nets in deep-sea fishery. Fig. 180 shows a more flexible type, with hemp-cored strands; Fig. 181 one with sixty-one wire strands, usual in ropes over 10 inches in circumference; and Fig. 182 a cable-laid rope, a now practically obsolete form. You will ob-

Fig. 180.

serve that the last is built up of six ropes, each resembling Fig. 178 in section.

After being tested, the wire is wound by boys on to bobbins, ready for the stranding-machines. The last have a strong family resemblance—a bobbin frame that revolves on a horizontal axis, through which the core, whether wire or hemp, passes. As the wires must not be twisted in themselves when

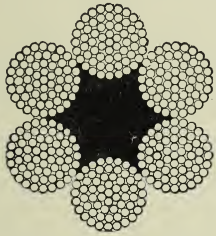


Fig. 181.—Sixty-one Wire-stranded Rope.

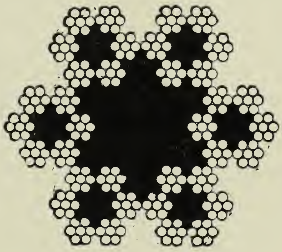


Fig. 182.—Cable-laid Rope.

laid together, it is necessary that the bobbins should maintain a horizontal position throughout their revolution, and this is effected by furnishing each bobbin-holder with a crank, which engages with a large collar turning on a centre set the length of the crank below the axis of the frame.

A general idea of a stranding-machine will be gathered from Figs. 183 and 184. The wires of a strand, or the strands of a rope, pass from the

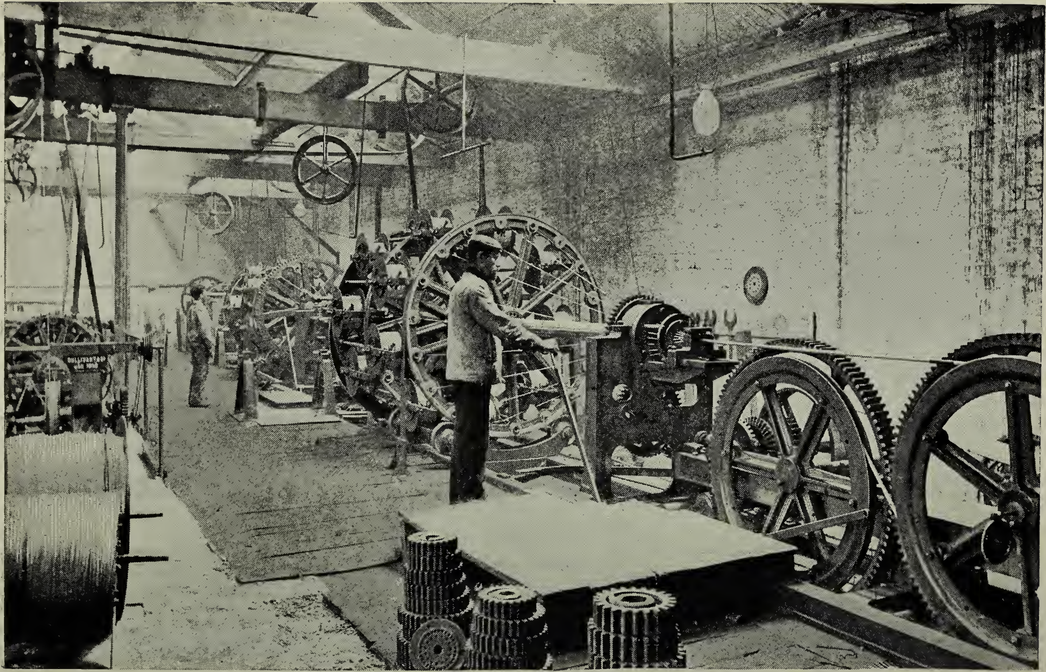


Fig. 183.—Machinery for twisting Steel-wire Ropes in three layers.
(*Photo by Bullivants, Ltd.*)

bobbins through holes in the wheel-like end of the frame, and are drawn together in a conical form towards the "nose," which is the extremity of the moving frame. A short distance from the nose is the "tube," a die which holds the wires sufficiently tight to allow them to be twisted together, but permits the strand to move on as it is laid. On leaving the die the strand passes over two large grooved wheels geared together, which exert the requisite pull, and then on to reels to be wound up.

In the case of a many-wired strand, as shown in Fig. 181, the wires are laid on in layers by as many machines, arranged "tandem," as there are layers. If the wires are of the same size throughout, the first machine twists six wires round the single-wire or hemp core; the second lays on twelve wires; the third, eighteen wires; the fourth, twenty-four—the strand of one stage becoming the core of the next. The machines revolve at different speeds, proportioned to the length of the "lay," the speed decreasing with every successive stage. In order to obtain a tapered rope, such as is used in some mines for winding the cages, bobbins are thrown out of action from time to time to diminish the number of wires in the strand.

The laying of strands into ropes is performed by

machines similar to the strand-makers, the only difference being that they are furnished with but six bobbins. The largest rope-closing machine is such a monster that I pitched my camera near it, and an obliging workman stood alongside to afford a stand-

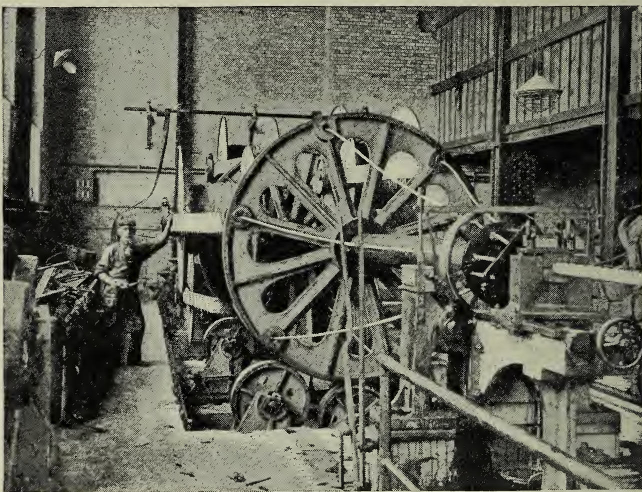


Fig. 184.—A monster Steel Cable-maker. It weighs 20 tons.

ard by which to gauge the size. This machine closes ropes of 60 tons weight; and as all the material for a rope must be wound on the bobbins before the closing commences, the total weight of strands and frame may reach 80 tons. Yet the whole turns round so quietly and easily that to the casual onlooker

it would seem as if little power were required to produce the motion. Mr. Bullivant told me that these very large ropes, which may have a length of over ten miles, are transferred, as fast as made, direct from the machine to barges lying alongside the wharf, and

Fig. 185.—Splicing a Steel Wire Rope.

coiled snugly up in the holds, after being well lubricated. The splicing of a big rope round a thimble appeared to me a very tangled and difficult operation; but the workmen made light of it, tucking in a strand here and there, twisting it about among its fellows, beating the joint with heavy mallets to make

everything snug, and "serving" the splice over with wire or hemp.

An instrument that interested me greatly was a hydraulic rope-cutter. Any one who has had to sever a large steel rope with a chisel and hammer

Fig. 186.—Cutting a 9-inch Steel Rope with a Hydraulic Cutter.

or other tools knows how tedious a job it is, owing to the tool being jammed by the wires that have been cut. In order to save time in an operation which is necessarily of frequent occurrence in the works, Messrs. Bullivant invented the apparatus named. Its principle is that of the hydraulic press

—a small pump injecting liquid into a cylinder of much larger bore and driving out a ram. The pressure used is about 7,000 lbs. to the square inch. By way of illustration, a workman took a length of 9-inch (in circumference) rope, inserted it in the jaws of the cutter, and began to pump. At the end of forty-two seconds by the watch the last strand had been severed. Formerly it took four men about an hour to cut a rope of this size by hand. The firm supply a special apparatus for submarine work, the pump being connected with the cutter by hydraulic tubing. If a hawser gets foul of a ship's propeller, a diver is sent below to affix the cutter and give a signal to his mates above, who pump away till the jaws have done their work.

This chapter may well conclude with a reference to the biggest steel rope ever closed on the premises —one 21 inches in circumference, warranted to stand a strain of 1,500 tons. I saw a piece of it, and wished I had been there to watch the making.

Chapter XXIX.

KNIVES AND RAZORS.

Early mentions of Sheffield knives—The making of a table-knife—Forging—Welding on the bolster—Drawing out the tang—Hardening and tempering—Grinding—Hafting—Inferior knives—Pocket-knives—Razors—Hollow-grinding—Etching.

IN his description of the Saxon swineherd Gurth, who figures prominently in the opening chapter of "Ivanhoe," Sir Walter Scott says: "The jacket...... was gathered at the middle by a broad leathern belt, secured by a brass buckle......In the same belt was stuck one of those long, broad, sharp-pointed, and two-edged knives, with a buck's-horn handle, which were fabricated in the neighbourhood, and bore even at this early period* the name of a Sheffield whittle."

Chaucer, in his "Canterbury Tales," written in Edward the Third's reign, has the line—

"A Sheffield thwytel bare he in his hose."

Two hundred years after Chaucer's death the Earl

* The reign of Richard the First.

of Shrewsbury gave his friend Lord Burleigh a case of Sheffield "whittells;" and it was with a knife of Sheffield make that Felton stabbed the Duke of Buckingham at Portsmouth in 1628.

For the last four centuries Sheffield has been the great centre of the manufacture of cutlery, a term which in its wider meaning includes all instruments with a cutting edge, but is now generally restricted to knives, scissors, and razors, and, curiously enough, to forks and spoons and other things commonly associated in their use with knives.

In this chapter we shall confine ourselves to the manufacture of knives and razors of good class, which are the peculiar pride of Sheffield cutlers. The word "Sheffield" stamped on a blade was once a sure guarantee of high value; but now, unfortunately, the fact that the name is impressed by unscrupulous people on blades of foreign manufacture may give the purchaser ground for suspicion, if the name of a good maker be not also on the steel. Real Sheffield cutlery is still worthy of its old reputation.

Crucible steel, made from the purest Swedish bar iron, is the material employed for high-class knife and razor blades. It has a very fine grain, and is capable of being so tempered as to be at once elastic

and very durable. A good steel knife will outlast a number of inferior articles, and though it costs more in the first instance is cheaper in the long run.

THE MAKING OF A TABLE-KNIFE.

A table-knife is usually composed of a steel blade, welded to an iron "bolster" or shoulder, which at its lower end is drawn out into a "tang" or shank, for insertion into the handle. The tang is sometimes lengthened by the addition of a piece of stout iron wire (Fig. 187).

Let us watch the first stages of knife-making—the forging of the blade, bolster, and tang.

The workmen often work in pairs at their forges. One takes a piece of flat steel bar about $\frac{5}{8}$-inch wide and 3 inches long, and heats it to redness. His mate seizes it by an end in a pair of pincers, and lays it on the anvil, where they deal it blows alternately, gradually thinning it out from the base to the point, and from the back to the cutting edge. Not a stroke is wasted, and in a few moments the bar has been converted into a rough blade.

Then back to the fire it goes, to be reheated for welding to the end of a bar half an inch square in section. The weld is soon completed, and the

bar cut through half an inch from the base of the blade. After another heating, the blade is passed through a split iron block to have the bolster beaten up and centred. The end of the

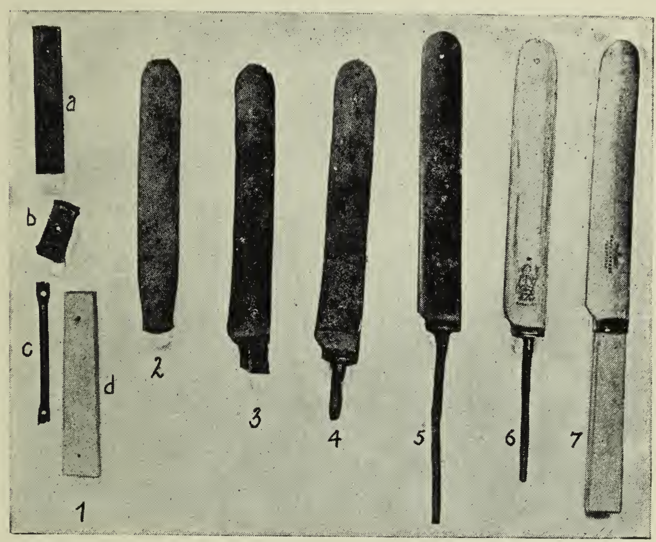


FIG. 187.—The stages through which a Knife passes. 1. *a*, Blade in rough; *b*, bolster; *c*, tang; *d*, haft. 2. Blade forged. 3. Bolster welded on. 4. Bolster drawn out. 5. Tang welded on. 6. Blade ground. 7. Finished knife.

bolster is then drawn out to a point; and after being placed in the fire again, the bolster is laid between two dies, called the "prints," and by blows on the upper die reduced to its final shape, with thin edges and sides curving towards the blade.

A piece of wire is welded to the tang, the maker's name is stamped on the blade, and the blade is well hammered till the edge is almost sharp enough to cut without further treatment.

The hardening which follows is effected by heating the steel and plunging it into cold water. The Sheffield water, by-the-bye, is credited—whether rightly or wrongly, one cannot say—with qualities peculiarly favourable to the process, and the workmen prefer much-used water to fresh. Then the blade is heated again, and allowed to cool till it has a certain colour before being dipped a second time. This gives it the correct temper for

GRINDING.

Knives are ground to-day in practically the same manner as they were ground in Chaucer's time. The grinder sits astride a large wooden block, or "horse," as he styles it, and with a piece of wood presses the blade against a large grindstone revolving in front of him and at the level of the "horse." His is a somewhat dirty task, as the fragments of damp stone which fly off coat everything in the "line of fire."

Upstairs, in the cutlers' shop, the bolster is ground

FIG. 188. - Forging a Blade.

(Photo kindly supplied by Messrs. J Rodgers & Sons. Sheffield.)

smooth and finished off on an emery-wheel; the blade is given a clean edge and polished; and the metal part of the knife is attached to the haft

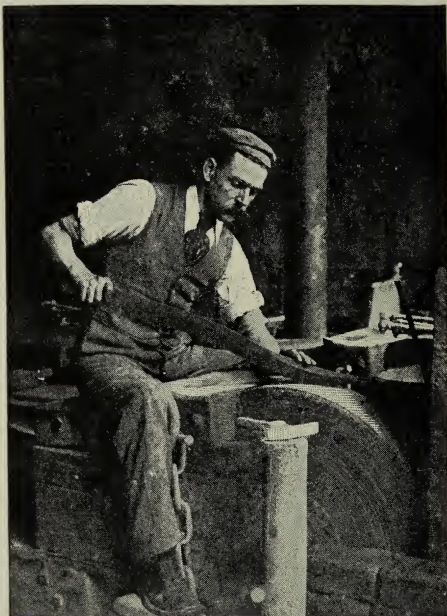


Fig. 189.—Grinding a Hunting-knife.
(*Photo kindly supplied by Messrs. J. Rodgers & Sons, Sheffield.*)

which has been pierced with a deep longitudinal hole for the reception of the shank. The knife is then finished.

Inferior blades are forged by machinery, and even

stamped out of steel sheets. The last method produces very poor stuff, as the blades, through lack of being hammered, wear very quickly, and are use-

Fig. 190.—Putting fine work on a Blade.
(*Photo kindly supplied by Messrs. J. Rodgers & Sons, Sheffield.*)

less long before a good hand-forged blade has begun to lose its original outline.

The blades of pocket-knives are forged in one piece, the bolster of the table knife being replaced

by a flat continuation pierced for the hinge rivet. The grinding is done in the manner described above; but the hafting is more or less complicated, according to the number and shape of the various parts. Some pocket-knives are real tool-chests in miniature, with saw, screw-driver, gimlet, bradawl, nippers, spike, cork-screw, scissors, wire-breaker, stone-hook, etc., added to a generous array of blades; and for their completion they may require the services of perhaps a hundred workmen.

RAZORS.

"Keen as a razor" is a proverb. A good pocket-knife may have a very sharp edge, but it cannot vie with that of a well-stropped razor. The whole secret of a razor's cutting power lies in grinding the blade very hollow, so that the edge half may be very thin and capable of being sharpened at an acuter angle than is possible with a wedge-shaped blade.

Hollow-grinding hails from Germany, where it was invented about the year 1870. English cutlers have now mastered the process so thoroughly that Sheffield produces some of the best razors made.

The forging of the blade and tang (usually made in one piece, though sometimes an iron tang is welded

on) includes the rough hollowing of the blade, an operation which some workmen manage so deftly that a "razor in the rough" may be usable if simply whetted. After forging, the blade is shaped on a dry stone, and sent back to the smith to have the back of the tang file-cut (to give the user a firmer grip), pierced with the rivet hole, and stamped with the maker's name. The blade is then hardened and tempered.

Grinding.—The blade is first ground lengthways on a stone with semicircular ribs projecting from the circumference, and afterwards cross-ground on a stone ranging from 6 inches to $1\frac{1}{2}$ inches in diameter, according to the hollowness required. It has then to be "lapped," or polished, crossways with emery on a wooden wheel, and "set" on a hone for use. Hafting calls for no special notice; but we may linger for a minute over the etching of the blade with the maker's name and, in some cases, with elaborate and beautiful designs. The design to be etched is prepared on a copper plate, the lines in which are filled with bitumen. A moist tissue-paper placed against the plate picks up the bitumen in the hollows and transfers it to the blade. An acid is then applied with a brush and

allowed to eat its way into the steel not covered by the bitumen, and when the latter is dissolved away by spirits of wine, the design appears as bright steel lines on a frosted background. If the letters have to be *sunk* into the steel, the transfer leaves

FIG. 191.—Finishing off Pocket-knives.
(Photo kindly supplied by Messrs. J. Rodgers & Sons, Sheffield.)

the surfaces where the letters are to come exposed to the acid and protects the surrounding parts.

The author is indebted to Messrs. Mappin and Webb, Ltd., of Sheffield for facilities given him for writing the above account from personal observations made in their factory.

Chapter XXX.

FORKS, SPOONS, AND HOLLOW WARE.

Smelting nickel ore—Pouring ingots of German silver—Rolling the ingots into sheets—Cutting strips off the sheets—Cross rolling—"Flying" blanks for forks and spoons—Stamping—An easy way of lifting a heavy weight—Pronging a fork—Filing—Bending—"Bowling" a spoon—Polishing—The electroplating room—Hollow ware—The parts of a teapot—Shaping the parts in a press—In the silversmiths' shop—"Raising" metal ware by hand out of flat plates—Engraving and embossing—Clever artists—Spinning metal sheets on a lathe—Wire-drawing.

FROM knives we may fitly pass on to forks and spoons, which are simple enough in outline, but require the employment of many machines for their production in large numbers. I owe Messrs. Mappin and Webb of Sheffield a debt for allowing me to witness in their works the whole process of manufacture of both these items of table furniture from the ore to the final polishing. The ore in question was nickel ore, a shining, heavy, gray substance, smelted on the premises to extract the nickel, which is mixed with copper and zinc to form the alloy called German

silver. This alloy is fashioned into forks and spoons, and heavily electroplated with real silver.

Let me begin at the beginning, which is the smelting-house. Here men, armed with tongs of curious shape, extract fireclay crucibles, filled with molten

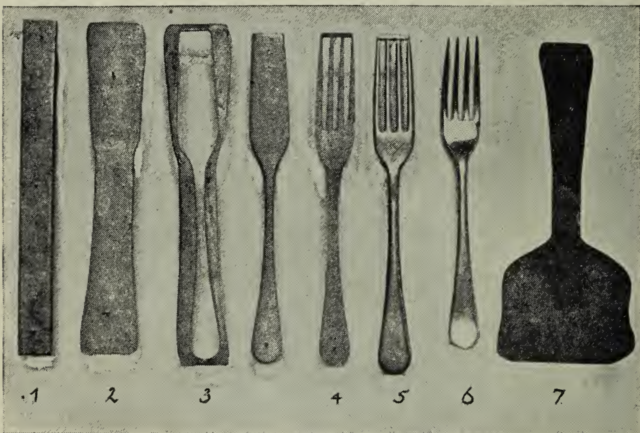


FIG. 192.—Stages of a Table Fork. 1. Strip of metal. 2. Strip cross-rolled. 3. Blank fork "flied out." 4. Fork pronged. 5. Fork stamped. 6. Finished fork. 7. Cross-rolled strip for a tablespoon.

metal, from holes in the top of a number of furnaces, and empty them into moulds to produce German silver ingots weighing 28 lbs. each. The operation requires great care, as a slip might send a flood of the white-hot metal over the legs of the workmen. A boy standing by throws a little powdered charcoal into the crucible at intervals to clear

away the fumes and show the workmen how far it has been emptied. It is a very hot business, and a strenuous one too, as the full crucible contains a hundredweight or more of metal.

When the ingots have solidified, they are extracted and sent on to the "breaking down" rolls, and considerably reduced in thickness. After this they are removed to a second set of rolls, and if for spoons and forks, are there finished to the required gauge.

The plates thus obtained are then transferred to *stripping-machines,* which snip off from their ends strips of the proper width for any particular shape and size of spoon or fork.

These strips have then to be treated by two rolls, which taper from the middle to the ends. Each strip is passed between the ends, and so cross-rolled or flattened out at each extremity, where the bowl or prongs, as the case may be, and the handle are to come. A cross-rolled strip for a spoon is shown in Fig. 192 (7); one for a fork in Fig. 192 (2).

Following the movements of the strips, we see them placed in a *flying-machine*—not one for aërial navigation, for which its great weight would indeed render it very unsuitable, but a magnified edition of the device used for stamping pens out of sheet steel.

Down comes a solid die, and all the metal required for a fork or a spoon is pressed remorselessly from the strip into the "bed" below.

In the *stamping-shop*, which we next enter, the blanks are laid in dies under heavy drop-hammers,

FIG. 193.—The Stamping-shop.
(Photo kindly supplied by Messrs. Mappin & Webb, Sheffield.)

and pounded until the edges of the shank have been rounded off. A thing in this shop that at first struck me as being peculiar was the ease with which mere boys raised hammers obviously weighing several hundred pounds by pulling at a rope. On looking closer, however, I saw that the pulley over which the rope

ran was kept continually rotating by steam power, and that all the boy had to do to lift the weight was to pull the rope sufficiently tight against the pulley for the friction to lift the weight; and by lowering the hands at a certain rate, to maintain the friction all the time the weight was rising. Immediately he raised his arms the rope slipped back over the pulley and the weight fell with a bang! So that after a little practice a boy can, aided by steam, raise a hammer much heavier than himself.

The fork has next to be *pronged.* The three spaces between the four prongs are stamped out separately by a mechanical punch. A strip about an eighth of an inch deep is left at the top of the prongs (Fig. 192, 4) to keep them from spreading under the next operation of *rounding,* which is effected by driving them into a sunk die with one of the hammers described above. The shank is then *marked* with the maker's name and any suitable design and handed over to a *filer,* who trims off all the rough edges caused by the stamping, and removes the cross-tie at the ends of the prongs. The prongs and head are then beaten by wooden mallets to their proper curve, and the shaping of our fork is completed.

A spoon undergoes the same operations, pronging

excepted, which is replaced by *bowling* in a lead mould under a hammer fitted with a rounded die. Some of the designs stamped on the bowl and shank are very elaborate and artistic. The edges of the bowl are ground flat on a stone.

The ware is then ready for the polishing which prepares it for the electroplating bath. Our guide leads us into a long room, where a number of girls, with their hair tied up in handkerchiefs to protect them from the dust, are busily polishing forks and spoons on humming "buffs" of wood and bristle. Every article is "roughed," "insided," "cleared," "swaged," "lined," and "dollied" with various substances before its surface has been brought to the resplendent brightness which one would never have thought could be imparted to the dull metal of the rolling-room.

PLATING.

The polished articles are now transferred to the plating department, and boiled in a solution of caustic potash to rid them of all traces of grease and dirt. Then follows a scouring in dilute sulphuric acid and aquafortis; and after this, immersion in a mercury bath, to give the surface of the metal a greater affinity for the silver it is to receive.

Silvering begins in a "starting" vat. The articles to be plated are suspended from copper rods connected to one pole of a dynamo, and supported by a frame which is mechanically shifted to and fro to keep the articles moving in the bath. When a good coating of silver has been deposited on them, the spoons and forks are taken out and scratched with fine wire brushes. The main part of the plating is done in the "dead" vat, where the articles remain several hours, until the prearranged quantity of silver—which varies with the quality of the article—has been deposited. This is ascertained by weighing an article and noting how much it has increased in weight since it entered the vat.

The frosty surface produced by electrical deposition is brightened by first burnishing it with steel tools, and then polishing it with rouge applied by the palms and fingers. No substance has yet been discovered that is superior to the human skin as a polishing pad.

In the wrapping and packing room we reach the end of our tour of inspection, and come into contact with sterling silver spoons and forks, which, by reason of being "genuine all through," have not had any experience of the plating vats. The rolling, "flying," stamping, and finishing being the same for

all kinds of metals, they call for no special mention in connection with silver plate.

HOLLOW WARE.

By the term "hollow ware" is meant such metal articles as teapots, vases, bowls, dishes, etc.—in short, vessels meant to hold liquids and solids. Messrs. Mappin and Webb make the manufacture of hollow ware a very important branch of their Sheffield business. In one of their large warehouses I was shown a number of queerly-shaped objects, which my guide informed me were the component parts of a teapot, ready for soldering together. Picking out the parts from different pigeon-holes, he quickly built up the rough resemblance of a "Queen Anne" teapot out of two *sides*, a *seat* for the lid, a *lid*, a *bottom*, and a *spout*. The last has two parts, so that in all seven parts, excluding small items such as handle, button, and hinges, are required for the construction of such an article. Some forms of teapots, I should mention, are less composite, the body and seat being formed from a single plate of metal, either by "spinning" it on a lathe or "raising" it by hand—processes to which we shall refer later.

It was further explained to me that all the various

seven portions named of the "Queen Anne" teapot were fashioned by moulding the plates of the metal used with heavy dies; and on my expressing the wish to see how it was done, we adjourned to the *stamping-room.*

Here were long rows of stamps similar to those

FIG. 194.—Getting in position the Dies for stamping a Bowl.
(*Photo kindly supplied by Messrs. Mappin & Webb, Sheffield.*)

used in shaping spoons and forks, but of a greater size. To initiate me into the mysteries of the art, a workman obligingly went through all the operations required for shaping a teapot side. He began by building a wall of clay round the edge of the deeply-sunk fluted die which took the place of

anvil, and poured in molten lead till it reached the top of the wall. When it had cooled he detached the mass from the die, and standing it over the die with the flat side downwards, let the 13-cwt. hammer descend on the rounded side of the casting. The under side of the hammer, perforated with holes, caught hold of the lead firmly enough to lift it.

He then produced a nest of metal "linings," which fitted into one another, and the outermost into the die. These, he said, were always used, so that the object to be moulded might be shaped gradually—the sharp edges of a bare die would cut a flat plate forced suddenly into it. After a few more blows of the hammer, to drive the lead "force" a little way down into the innermost lining, he placed a German silver blank in position and pounded it until it required annealing to soften it. Then followed more poundings, and the plate gradually assumed a shape that faintly suggested a teapot side, with flutings in a very sketchy form. Then lining after lining was removed, until the die was bared to the metal under treatment, the "force" gradually moulding itself to the shape of the interior. For the final shaping, my instructor made a *tin* casting in the mould, and laying it in the teapot side

brought down the "force" several times. The hard tin completed the process by squeezing the plate into all the recesses of the die and bringing out the design in sharp relief.

Soup tureens, dish covers, and other large articles are "drafted down" in the same way by a series

Fig. 195.—The Silversmiths' Shop.
(Photo kindly supplied by Messrs. Mappin & Webb, Sheffield.)

of lead "forces." For the heaviest ware a 24-cwt. hammer, capable of giving a 5-ton blow, is used.

In the *silversmiths' shop* the sides, cover, bottom, and spout of the teapot are wired together, red-heated on a bed of glowing charcoal, and soldered together—an operation which the workmen perform very dex-

terously. The rough edges of the various plates are then filed down flush, the lid is attached by hinges, and the handle is affixed. The teapot has then to be well cleaned and polished, electroplated, and polished again.

Raising is the conversion of flat plates into hollow

Fig. 196.—Raising Hollow Ware by hand.

ware by beating them on anvils with hammers and wooden mallets. This kind of metal-work demands great skill on the part of the workman, who in many cases is a real artist at his trade, producing original designs and shapes as the fancy takes him. The accuracy with which a large silver disc is transformed

into a deep bowl "by eye" cannot but impress the beholder. You could easily imagine, if you saw the bowl for the first time when finished, that a lathe had been used to shape it.

Engraving and *embossing* also come under the head of highly-skilled labour. It is a pretty sight to see some intricate design, such as a border of maidenhair fern, growing under the chisel of an engraver round the edge of a silver salver, or to watch him quickly cut a monogram, "freehand," on the centre. He sketches in deep, sunk lines as easily as, and much more accurately than, the average person could write or sketch with a pen. He hardly knows how to make a badly-finished stroke. Close by him is an embosser busy on a large bowl. He has to reproduce on its surface a design previously worked out on paper. The interior has been filled with a compound of pitch and plaster-of-Paris to offer a dead resistance to a blow, and prevent the metal from being unduly distorted. On the bench are a number of tin boxes containing upwards of eight hundred different steel tools, each of which he can distinguish easily from the rest, though to me many of them appeared to be exactly alike. Using now one and then another of these tools, he squeezes the

metal this way and that, sinking or raising it as he wishes, until a poppy-head with half-opened petals appears. This master of craft told me that he had attended art classes regularly for twenty-five years, and felt that the older he became the more

Fig. 197.—Embossing a Bowl.

he had to learn—a confession which gave me the key to his remarkable success as a worker in metal.

For the raising of high-relief designs on a deep vessel like a vase, into which a hammer cannot be introduced, a "snarling iron" is used—that is, a bar with two tapering arms bent at right angles to each

other, and turned up at the points. One arm is fixed vertically in a vice, and the article to be raised is slipped over the horizontal arm. A blow administered near the bend causes this arm to vibrate and press out the metal touching the end. Thus the difficulty is surmounted in a very ingenious manner.

Spinning.—I think that the most interesting thing I saw in the works was the "spinning" of sheet metal on a lathe into vases, teapots, fernpots, etc. Let me describe how a fernpot was spun. The workman attached to the mandrel of his lathe a circular wooden block, shaped to the interior of the bottom of the pot that was to be. Between the free end of this and the headstock of the lathe he centred a round plate of "white metal," and screwed the headstock up to keep the two together. As soon as the lathe was set going he placed a little peg in a hole in a rest, and used it as a fulcrum to press a tool against the metal disc and bend it towards the block. Almost as if by magic the metal turned over and formed a cup, the sides of which he smoothed down against the wood. Then he removed the mould and replaced it with a hollow chuck to hold the cup by the bottom and leave the edge free. The last he quickly turned inwards and then outwards, to make a graceful neck, which

he kept on working till it fitted a profile plate held against it. The whole operation lasted but a very few minutes. Then he spun the body of a teapot, and afterwards a large metal alms-dish. It looked a delightfully easy process, and no doubt he found it so, thanks to his long experience.

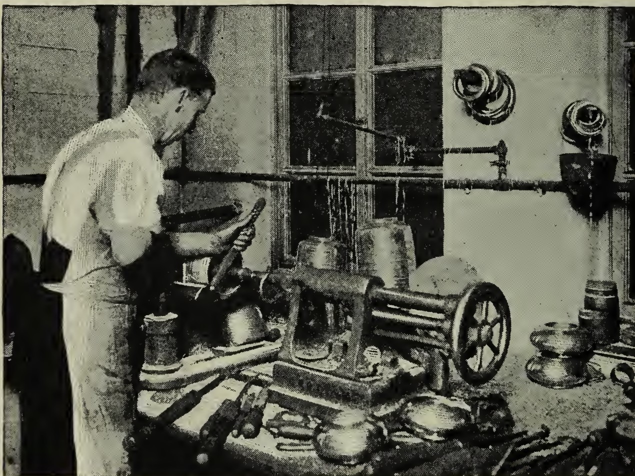


FIG. 198.—"Spinning" a Bowl out of a metal disc on a lathe.

Many kinds of hollow ware are built up of several parts. A cup, for instance, may be composed of the cup proper, the shaft, and the base, each of which has to be fashioned separately. A bowl often has an ornamental beading welded along the edge to improve

its appearance. Such a beading is made by passing a strip of metal between two rollers—one plain, the other with the pattern sunk into its circumference Wire, which also plays an important part in the embellishment of silver ware, is obtained by drawing a square strip through a circular hole in a solid plate.

And here I shall have to conclude this chapter, though I saw a number of other interesting workshops at Messrs. Mappin and Webb's which I should have liked to describe had space permitted.

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NOTE.—Figures in italics signify that an illustration of the thing referred to appears on the page.

THE END.